NUCLEAR ENGINEERING

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Editor:
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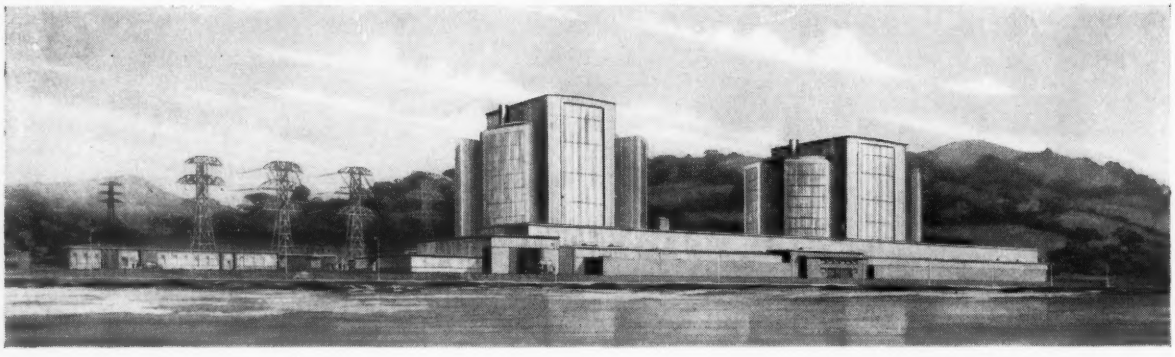

An artist's impression of the new nuclear power station

Britain leads the world in nuclear power for peace

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NUCLEAR ENGINEERING VOL. 2 NO. 10 JANUARY, 1957

EDITORIALS

Commercial Power Stations

WHEN the concept of forming consortia headed by the major electrical generating plant manufacturers in the country was first projected, it was considered necessary to introduce a competitive aspect into the production of nuclear power and to share experience with the maximum number of industrial organizations, whilst limiting the educational commitments of the A.E.A. to a workable minimum. It was envisaged that the introduction of nuclear power would be relatively slow and that the four consortia would have a real incentive to compete for the first contract that would be awarded by the electricity authorities. It was assumed that the development of designs would be accomplished at a varying rate, so that the awarding of contracts could conveniently keep pace with the progress of the groups.

There is little question that the incentive of a first contract award has been more than adequate and concomitant with steady improvement in design performance of Calder Hall quality of designs for these first stations has been remarkable. Each consortium has put in a tremendous effort on the design and development and each has been able to submit tenders which show a notable advance on the Calder Hall prototype. During this development and design process, it has been obvious that the original programme laid down by the 1955 White Paper, at the time considered optimistic and ambitious, was in fact inadequate, and whereas tenders for one station in the early days was contemplated finally three tenders from each of the groups have been considered—for Bradley, Berkeley and Hunterston. The net result, therefore, has been that the balance has moved from the selection of the most suitable design to the elimination of the least suitable. One unfortunate corollary of this has been that instead of kudos for a single group it is dispraise. This aspect has been tacitly acknowledged in the urgency that has been brought to bear on the agreement for a fourth site at Hankley Point, and the English Electric group is assured of this contract in the near future.

Quite apart from the determination of the basic parameters and the development of the detailed designs which followed, the consortia have been faced with a very difficult problem in the philosophical approach. Whereas there was an urge to produce imaginative designs incorporating the greatest advances which could be conceived, this had to be balanced against prudent conservatism in which technical advances were limited to only minor extrapolations from the familiar. Not only did these have to be weighed in terms of ultimate reliability and economy, but also in terms of the views of the examining committees. It is difficult enough to decide what is adventurous and what is foolhardy and what is prudent and what is unenterprising, but these decisions had to be taken in the light of the probable opinions of a second party. Probably the greatest difference between the various designs lies in this philosophy of approach with the G.E.C. and English Electric groups forming the extremes.

It is generally acknowledged that the decisions independently taken by the C.E.A. on the advice of the A.E.A. and the S.S.E.B., who have employed Kennedy and Donkin as their main consultants, avoided the uncomfortable situation in which neither authority was prepared to forgo the designs of one of the consortia. Between these examining bodies there has clearly been a sufficient difference in philosophy to cause them to select different designs from the four submitted. The C.E.A. has chosen the middle course, whereas the S.S.E.B. has opted for the most ambitious design of all. This difference in philosophical approach is of particular interest when taken in conjunction with the unanimity of opinion that was expressed inside the two examining bodies. Never can any tender have been more thoroughly and more rigorously gone into than the tenders for these first stations. The best brains of the country could be engaged to sort out the optimum system. Considerable foresight was exercised in the organization of the investigation and nothing short of the highest praise is due to those responsible.

It should be borne in mind also that, whereas the tenders were received on October 1 and the technical examinations were completed during November, this is not to say that only six weeks have been spent on the examination. The mass examination was the culmination of many months of co-operative assessment and consultations between the designers, consultants and the authorities.

We in the U.K. can be properly proud of these tenders and the advances in reactor technology that they show. The whole picture of atomic energy development and of the prospect of economic nuclear power on a large scale has been dramatically altered by their quality and great credit accrues to the four consortia and the A.E.A. for the intensive and excellent effort that they represent.

The Electricity Bill and Power Costs

THE second reading on the Electricity Bill was carried without a division in the House of Commons on December 17. In moving the second reading, the Minister of Fuel and Power referred to the Herbert Committee report of February last, in which the conclusion was reached that the responsibility for the generation of electricity and supply in bulk should be divorced from the general responsibility over the entire industry. This has been taken into account in the drafting of the Electricity Bill, which provides for a Generation Board directly responsible to the Minister and an Electricity Council independent of the board; the area boards are to have a greater degree of autonomy. Because of the increasing accent on generating electricity from atomic energy, it is imperative that the new generating board should be closely in touch with developments in nuclear power. It is suggested that two members of the A.E.A. should be part-time members of the generating board and it is likely that the chairman or one of the deputy chairmen will have a background of atomic energy experience.

It was believed at one stage that the Minister would simultaneously announce a rapid expansion of the nuclear power programme, but Mr. Jones was careful to point out that a tremendous investment programme is necessary and it was important not merely to double or treble figures on paper but to speed up the industry. Break-downs of the capital costs of these first industrial designs are not available and a final assessment of cost in terms of pence per kWh cannot be made until further experience has been obtained and until a less hypothetical price can be fixed for plutonium. Furthermore, in the consortia's own analyses of their own designs there has been some variation in the degree of optimism displayed in terms of operational temperatures, design margins and other figures which can affect total output. Attempts have been made to reduce these different estimates to a strictly comparable basis, but no two people would agree exactly on the method. It is evident that the accepted tenders quoted capital costs which fell within the range £125-£135/kW which, when added to the Authority's costs, will raise this by a few pounds per kW to accord with the statement issued to the effect that the C.E.A.'s first three stations, with an output of 850 MW, will cost not less than £120 million. Taking fuel costs that are on the pessimistic side, it is almost certain that the cost of generation will fall within the range 0.65 to 0.75 pence per unit sent out. The statement by the C.E.A. that the capital costs will be not less than two and a half to three times that of a comparable coal- or oil-burning station would appear to imply highly optimistic capital costs for conventional stations and would appear also to be less relevant than the S.S.E.B. statement that the overall cost per unit generated would be competitive with that of a corresponding coal-fired station.

New Graphite Industry

IT has been announced that a new British company, to be called Anglo-Great Lakes Corporation Ltd., has been formed to set up a reactor-grade graphite manufacturing plant on Tyneside. The factory, which is estimated to cost £6 million, will be located alongside the Stella North power station at Newburn Haugh, near Newcastle. Excess generating capacity is available at this power station, large quantities of cheap power being a prime essential for the production of graphite at an economic price.

The factory, which will employ about 500 men, is hoped to go into production by December, 1958; initial work on construction will begin this year. Production, which will be increased in three stages to keep pace with the growing nuclear power programme, will initially be 15,000 tons/year. Taking as an approximate figure for the Calder Hall type reactor of 12 tons of graphite per MW installed capacity, the output would meet a nuclear power station programme of 1,200 MW new plant per year, a significant proportion of the total anticipated; present estimates indicate that a yearly additional installed capacity of 2,000 MW (including both conventional and nuclear) is required to meet increasing demands.

So far the production of graphite for atomic-energy purposes in the U.K. has been handled by British Acheson Electrodes Ltd., in collaboration with the Atomic Energy Authority. It should be noted that the U.S. counterparts of British Acheson and the Great Lakes Carbon Corporation are the major competitors in the U.S. graphite market. The study of techniques for the manufacture of reactor-grade graphite has received considerable assistance from the A.E.A., and it is laid down that all marketing of graphite in and from the U.K. for atomic-energy applications shall be made through the A.E.A. It is understood that in this respect there will be no difference between British Acheson and the new company, and that at the present time a free market in graphite is not contemplated. Furthermore, equal facilities available in the A.E.A. for the testing of graphite samples will be made available to the new company.

It had been hoped that the establishment of competitive production facilities for graphite would have enabled this important commodity for the reactor power programme to be established on normal commercial lines, but apparently it is thought at this stage that a close Government control must still be maintained. The conclusion cannot be avoided, that as the new company will be closely associated with four members of the Nuclear Power Plant Company, that this consortium will be in an advantageous position should the supply of graphite at any time become difficult. On the other hand, the existence of this new company should imply that, for the time being, future supplies are now assured. Two other companies, however, are known to be interested in graphite, so further developments can be expected.

Comments on the News

U.S. FUEL PRICES

The announcement by the President of the U.S.A. on November 18 concerning changes in the supply of nuclear materials can have far-reaching effects on the developments of atomic energy outside the U.S. and on the export of power units from that country. In February of last year the Atomic Energy Commission was instructed to make available 20,000 kilograms of uranium-235 for distribution abroad. Whilst this was an important step towards the creation of a commercial market in uranium, the terms under which such releases could be made were viewed with some suspicion by the prospective customers. In October, for example, it was reported that Switzerland, having concluded a bilateral agreement with the U.S., was still dissatisfied with the limitations imposed on the use of fissile material and was seeking to conclude an agreement on more open terms with the Soviet Union. The new policy seeks to convince outside nations or groups of nations that fuel supplies necessary to the continued operation of nuclear power installations will be assured and brings prices for such fuel into line with those charged within the U.S. Provision has been made for prices to be standardized not only for the sale of uranium but also for the U 233 or plutonium returned in spent fuel elements, together with unused U 235.

Charges for fuel are a function of enrichment varying from $5½ per gram for natural uranium up to $17 per gram for uranium enriched to 90%. These figures quoted are for the U 235 content of the fuel. Fuel with 20% enrichment, for example, will cost $16 per gram U 235 or $80 per gram total uranium. The U.S. is prepared to furnish U 235 in specified quantities based on the established fuel requirements of a given power installation over a fixed period beyond the present term of ten years. The value of plutonium and U 233 has been set at $12 and $15 per gram respectively. The customer is required to pay for the necessary processing. Prices are to be guaranteed for a period of seven years, a rule which up to this time had applied to internal commitments only. Certain details have remained unchanged—such as the charges for heavy water and for natural uranium which remain at $28 per lb. and $40 per kilogram respectively—but other details have been modified towards greater flexibility. It should be noted that for any quantities exceeding 6 kilograms, U 235 enrichment is limited to 20%. The U.S. is already committed to supplying 1,700 kilograms of U 235.

The agreements under which these sales can be made, whilst containing a clause which may allow reprocessing to be performed in facilities other than those owned by the U.S., still make provisions to ensure that the material is not diverted to military purposes. The chief stumbling-block in the past, however, has been the possible dependence on the political situation for future supplies rather than any serious wish to have complete control over the use to which the material was to be put, and undoubtedly this announcement will go a long way towards convincing prospective customers that these fears are now unjustified. In effect, therefore, utility companies abroad will be able to assess the respective merits of reactor systems on technology and cost alone. We must be sure that prospective customers are made aware that similar assurances would be given by this country to importers of British power plants. Such assurances are probably not as essential, as for the time being British systems will use natural uranium, but we must be careful that no doubt lingers on the availability of a continuous supply of fuel elements.

FUTURE DEVELOPMENTS

Some indication has been given in the past few weeks of the future interest of the established consortia. Hints were given by representatives of each of the four big groups at the B.N.E.C. symposium in November on the type of development that they regard as most likely to be significant in the near future. It is probable at this stage that this represents an indication only, and it should be acknowledged immediately that all groups have research departments engaged on investigating the various problems of, say, liquid-metal coolants, water corrosion, high-temperature operation, etc. Furthermore, the groups are committed to further development of the graphite-moderated, gas-cooled system. Whilst the designs submitted to the C.E.A. represent a marked improvement on the Calder Hall design, they do not by any means represent the ultimate limit to which these designs can be taken. In the first place, straight engineering design improvements will allow the capital cost to come down appreciably and this is probably the most important aspect of their design development. Because of limited time and limited experience, it has always been necessary to play safe and hence indulge in designs which are relatively costly. As one senior member expressed it: in order to produce the best designs one must live with the problems for a long time, and so far there has been no time to really live with them; but the design experience in preparing tenders has already provided the background from which further designs can be developed. Secondly, improvements in constructional materials will allow an overall increase in the temperature of operation, with a consequent considerable improvement in the thermal efficiency of the plant. Beryllium is likely to play an important part in these developments and an easing in the availability of enriched material will also probably have its effect. These two types of development should allow a progressively decreasing cost without any fundamental change of system.

As a second string, however, it is known that A.E.I.-John Thompson Nuclear Energy Co. Ltd. have a particular interest in the high and very high-temperature gas-cooled reactor and it has been reported that Metropolitan-Vickers are already engaged in the preparation of preliminary loop designs under contract to the A.E.A.. The G.E.C. have implied that there are distinct advantages to be gained by using liquid-metal coolants and although at one time the sodium-cooled, graphite-moderated reactor might have been uppermost in their thoughts, it is understood that this is now being treated with greater reserve. Babcock and Wilcox Ltd. have already a stake in the pressurized-water field and their contract for the construction of the NPD pressure vessel will probably not be their only excursion into this type of reactor system. The N.P.P.C. have stated that they regard the improved Calder Hall type as providing a possible answer to the medium-sized reactor (maximum 100 MW generating capacity), but it is known that they are also interested in liquid-metal developments and that the developments at Dounreay are being watched closely.

VALUE OF "NAUTILUS" EXPERIENCE

At the meeting of the Joint Nuclear Marine Propulsion Panel at which a paper by Mr. C. P. Boadle on "Some Safety Considerations of Nuclear Power Reactors" was read, it was clear that the operational experience of the *Nautilus* had made a deep impression. It was urged that similar operational experience should be obtained in the U.K. to provide data for the development of economical units for merchant ship propulsion. However, the point was made that one of the major contributing factors to the success of the *Nautilus* was probably the extensive land-based testing that the propulsion unit received. Too great an emphasis can be placed on the *Nautilus* experience at sea and the implied lead this gives to the U.S. in the development of an economic propulsion system for civil work. Where the cost of propulsion is of secondary importance, the value of this experience is undeniable, but for merchant ship applications, only if a very similar type of reactor system is finally adopted will this experience provide detailed information.

It should not be difficult to obtain practical experience on representative control systems by installing them in ships and causing them to operate simulated reactor systems. Such an investigation can be undertaken in the very near future and valuable design data and operational experience obtained without incurring both the development time and cost of building a propulsion unit. Also, a number of experimental systems can be set up and tested alongside each other, whereas in a nuclear-powered ship decisions must be taken before operational experience has been gained, and the control system cannot necessarily be chosen to typify systems which will be applicable to other reactor systems. It would be unfortunate to commit ourselves at this stage to building a ship installation before adequate land-based testing had been performed. As with the *Nautilus*, much of the experience gained would be inapplicable to more advanced reactor units. It would seem, therefore, that at this stage, whilst consideration should be given to the problems associated with the mounting of a reactor in a ship, a start could be made immediately on the preparation and testing of various control systems and in the preparation of suitable land-based experimental facilities which can simulate, at least in part, the peculiar conditions experienced at sea, for the testing of small-scale reactor units.

HARWELL CONFERENCE

In contradistinction to the Shipbuilding and Shipbuilders conference at Harwell, the unsatisfactory nature of which was mentioned in last month's comments, the conference between the Atomic Energy Authority and 200 representatives of British industry on the future reactor systems for nuclear power has been unanimously praised. Perhaps one of the most significant contributions that this conference made was to underline the differences of opinion that are current in the optimum system for Stage 2 and 3 development. Industry was able to hear senior representatives of the various reactor projects discussing the advantages of their own particular system with sincerity and conviction. Senior members from the same station were earnestly pressing different reactor systems with equal confidence. This, in some ways, was perhaps confusing to those members of industry who were hoping for a direct lead on the developments most likely to be successful in the future, but a real service has been given in emphasizing that this at the present time is not known.

There is universal agreement that it is imperative that work begins in the near future on a number of reactor systems in order to obtain design experience, because it is only by this design and constructional experience that final decisions can be taken. Trends in the past few months indicate that the organic-moderated system is liable to have associated with it less development problems than was at one time anticipated, and a strong body of opinion at Harwell and in other sections of the Authority believes that cooling by gases is likely to remain the optimum system for many years. It is expected, therefore, that experimental design work on the very high-temperature gas-cooled reactor will not be long in starting and that once beryllium technology is further advanced attention will be focused on materially increasing the output temperature of the Calder Hall type. At the same time, enthusiasm for the sodium-cooled, graphite-moderated reactor is decreasing and it is unlikely that any decision to go ahead with this type will be made before the end of this year. The protagonists of the homogeneous reactor and liquid-metal-fuelled reactors both have their strong followings of support, and it is expected that experimental work on these will begin this year. Water-moderated reactors already form part of the submarine programme and large-scale development will no doubt await the preliminary results of these investigations. Similarly, work on the Dounreay fast reactor is continuing and commissioning trials are expected within the next 12 months. Apart, therefore, from the sodium-cooled, graphite-moderated reactor which has been losing support, all other systems would appear to have their particular place in the programme, and the deciding factors on the rate of development of each type will largely be a matter of the finance and personnel available. We can be certain, however, that the high-temperature gas-cooled reactor will be in the forefront of new developments. The future position of the gas turbine as the prime mover in these systems is a matter for conjecture, as listeners to Mr. Wootton's defence of steam at the B.N.E.C. symposium would appreciate.

SWEDISH DEVELOPMENTS

When it is remembered that hydro-electric generation should, at present estimates, be able to supply the majority of Sweden's electricity demands until 1980, the present programme of the Swedish State Power Board must be considered both imaginative and far-seeing. Total annual production at present amounts to 28,000 MkWh, of which 95% is based on hydro-electric schemes. Full exploitation of the hydro-electric potential is estimated to give an annual supply of 80,000 MkWh. Annual increase in demand is somewhat lower than for other European countries, amounting to 6.5% per annum, and on these figures the hydro-electric capacity will not be exceeded before 1980.

However, to make provision for the time when these resources have been fully exploited, and bearing in mind the lack of indigenous fuels, Sweden has already undertaken the building of two nuclear power stations which are expected to be in operation by 1960 and 1963 respectively, so that experience may be obtained on this form of generation. The first unit, named Adam, will not be used for generating electricity and is a research reactor generating some 75 MW heat. It will almost certainly be a heavy-water-moderated reactor fuelled with natural uranium and will form the basis of future research and materials testing. No decision has yet been taken on the design of the 100-MW electrical capacity nuclear power station provisionally termed Eva, and no doubt development in the U.K. and the U.S. and Canada will be followed closely.

Comparison of the Industrial Designs

A brief comparison is made of the nuclear power station designs prepared by four groups of companies for inclusion in their tenders to the Central Electricity Authority and the South of Scotland Electricity Board for the erection of generating stations at Bradwell in Essex, Berkeley in Gloucestershire and Hunterston in Ayrshire.

BERKELEY—A.E.I.-John Thompson Nuclear Energy Co. Ltd.
BRADWELL—Nuclear Power Plant Co. Ltd.
HUNTERSTON—G.E.C.-Simon Carves Atomic Energy Group

THE designs submitted by the four industrial groups have all been based on the Calder Hall plant as a prototype, but there are many points of detail which differ substantially from the Calder Hall design and in all cases a large advance in power output is offered.

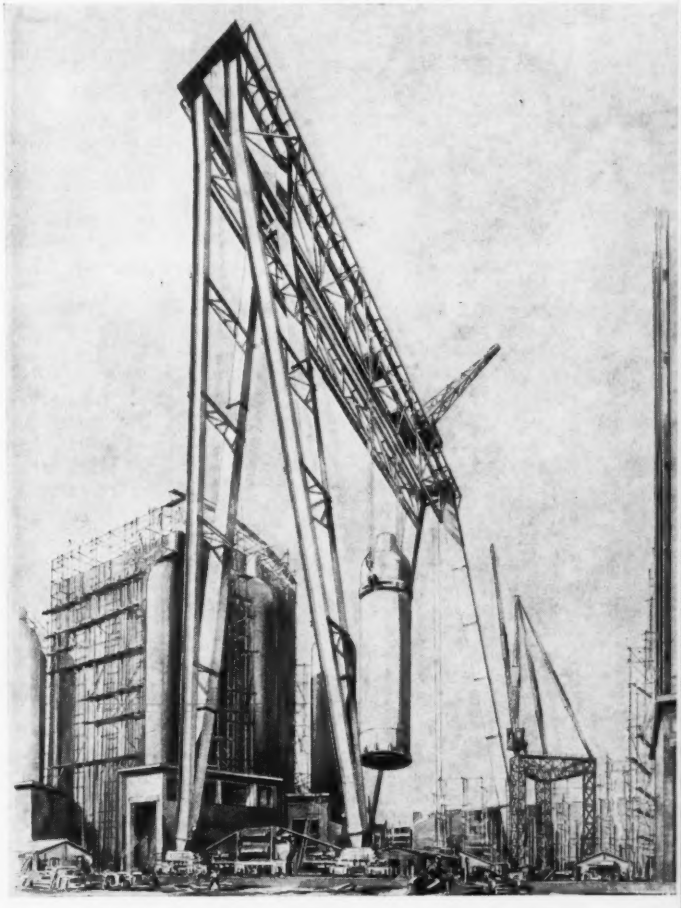
Perhaps the most notable advance in design concerns the size and heat output of the reactor core. All four groups propose a heat output of more than 500 MW from a single reactor, and this is to be achieved by employing a core of larger diameter and by using a greater degree of flattening than at Calder Hall. The increase in the heat rating has also been aided by the use of a higher gas pressure and by a slight advance in the permissible maximum fuel-element temperature from 408°C, as at Calder Hall, to 420°C or more. The major factor in increasing the total heat output, however, has been the relatively large increase in the core size.

From an operational point of view, the most signficant advance in the new designs is the introduction of fuel changing under load. This, again, is a feature common to all four groups, although the method by which it is to be achieved differs from one design to another. The fact that satisfactory designs have now been prepared for fuel-handling machinery which will enable the charging and discharging of fuel elements to be carried out under full load, and without any interruption to the operation of the plant, may prove to be one of the most important factors in establishing the superiority of the gas-cooled reactor over other designs. It is not always appreciated that the need to shut-down in order to change fuel elements is one of the most serious objections to existing designs for liquid-cooled reactors.

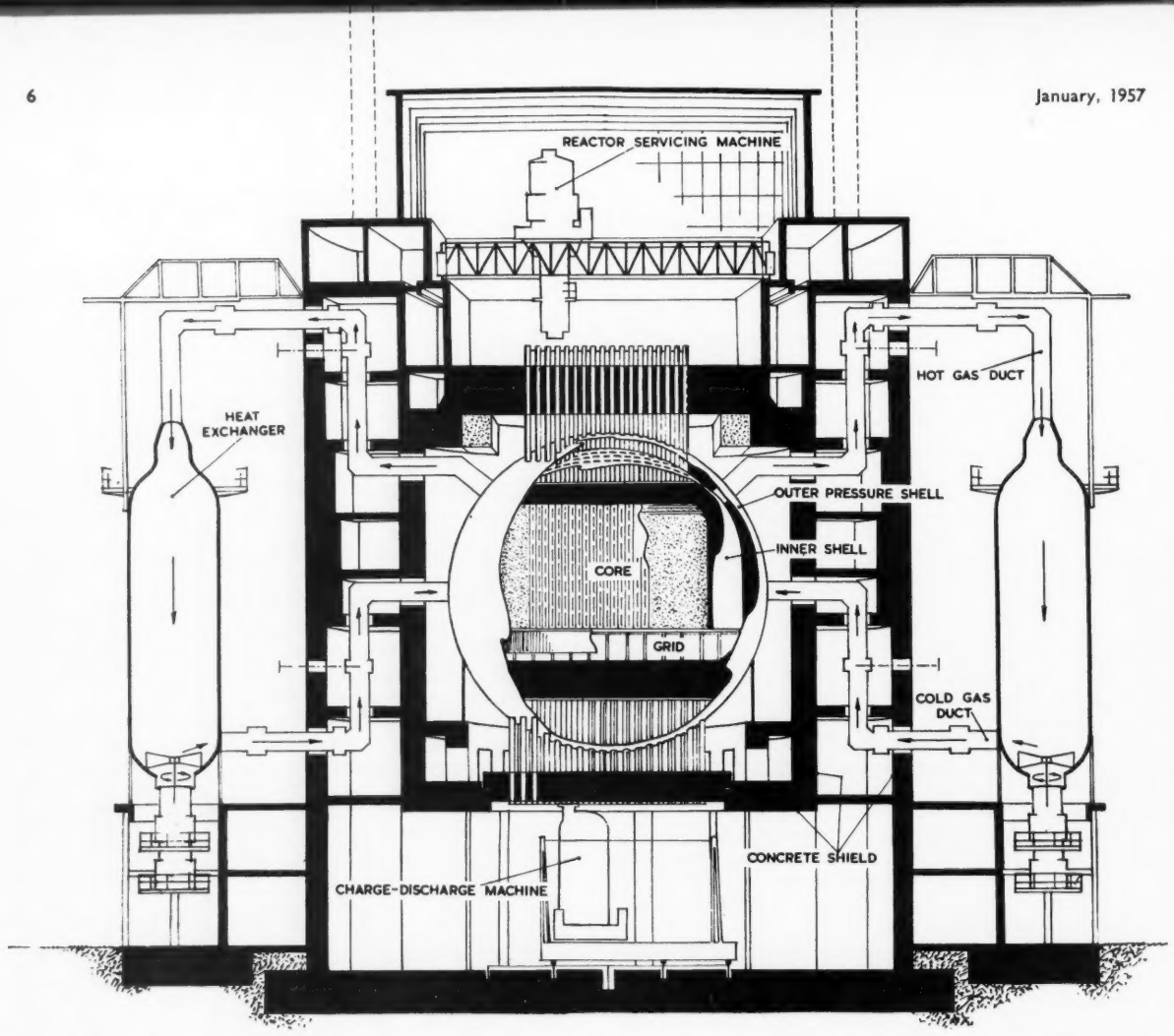
In general, the materials of construction proposed are similar to those used at Calder Hall. This may be regarded as a wise decision and it will mean that the experience gained at Calder Hall will enable a firm guarantee to be given for the behaviour of most of the materials to be used in the new plants. The choice of entirely new materials would have introduced an element of uncertainty into the predicted performances, but as things stand at the moment the advance is being achieved primarily by improvements in the mechanical engineering and by developments in fabrication and other constructional techniques.

The increase in the size of the reactor core and the use of higher gas pressures have introduced considerable problems in the design of the pressure vessel. Three out of the four groups have chosen a spherical vessel, the range of diameters being 60 to 70 ft. The A.E.I.-J.T. group, on the other hand, has retained the cylindrical arrangement as at Calder Hall, but with a diameter of 50 ft. using steel plate of 3 in. thickness. The only disadvantage of the sphere is the greater extent of the concrete biological shield. With a spherical design of pressure vessel a skirt type of support becomes feasible and this arrangement has been proposed in the E.E.B. and W.-T.W. and in the G.E.C.-S.C. designs. In the other two designs a column type of support, not unlike the Calder Hall arrangement, has been chosen.

The design of the graphite core in general follows that of the Calder Hall reactors, with the exception of the



An impression of the Hunterston station as it will appear in the course of erection. In the foreground is the Goliath crane with a span of 200 ft. and a lifting capacity of 300 tons.



G.E.C.-Simon Carves reactor system. Most notable departure from existing practice is the bottom charge and discharge facility.

G.E.C.-S.C. plant where some changes have been necessitated by the choice of bottom charging. A major departure from Calder Hall, however, has been made by three of the groups who have worked on the principle of individual support of fuel elements; the method of support, however, varies considerably. G.E.C.-S.C. employ a graphite sleeve which is loaded with the fuel element. A.E.I.-J.T. use graphite struts with zirconium end brackets. E.E.-B. and W.-T.W. use a zirconium spider with collapsible legs. The N.P.P.C., alone of the four groups, has retained the simple expedient of stacking fuel elements one on top of the other in the channels. The stacking arrangement has the obvious virtue of simplicity, but the opponents of stacking have doubts as to the behaviour of the fuel elements under prolonged irradiation. Bowing or distortion of the lower fuel elements in the channels, as a result of creep, may impose a limit on the permissible irradiation of the fuel.

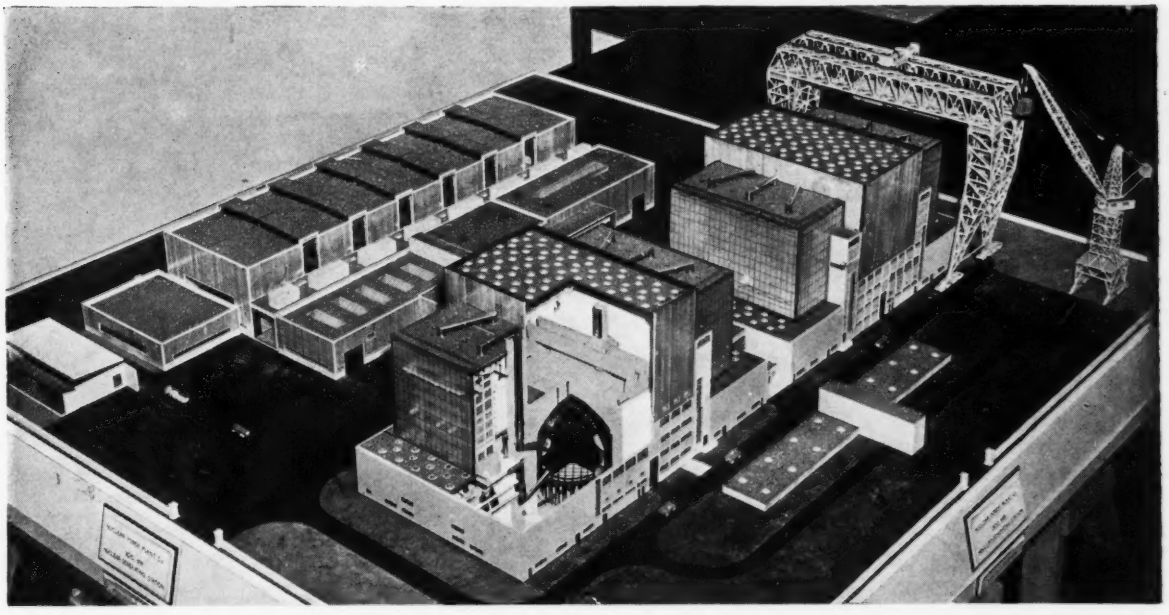
Three out of the four groups have adopted what may be regarded as the normal arrangement of charging and discharging from the top of the reactor, although, of course, the design of the charging and discharging machinery differs from one scheme to another. G.E.C.-S.C., however, have broken away completely from orthodoxy and have introduced charging and discharging of fuel from the bottom of the reactor. This results inevitably in a somewhat complicated charging machine, but the other advantages are considerable and, since access to the channels can also be provided at the top of the reactor for special purposes, this design would appear to represent a considerable advance on Calder Hall.

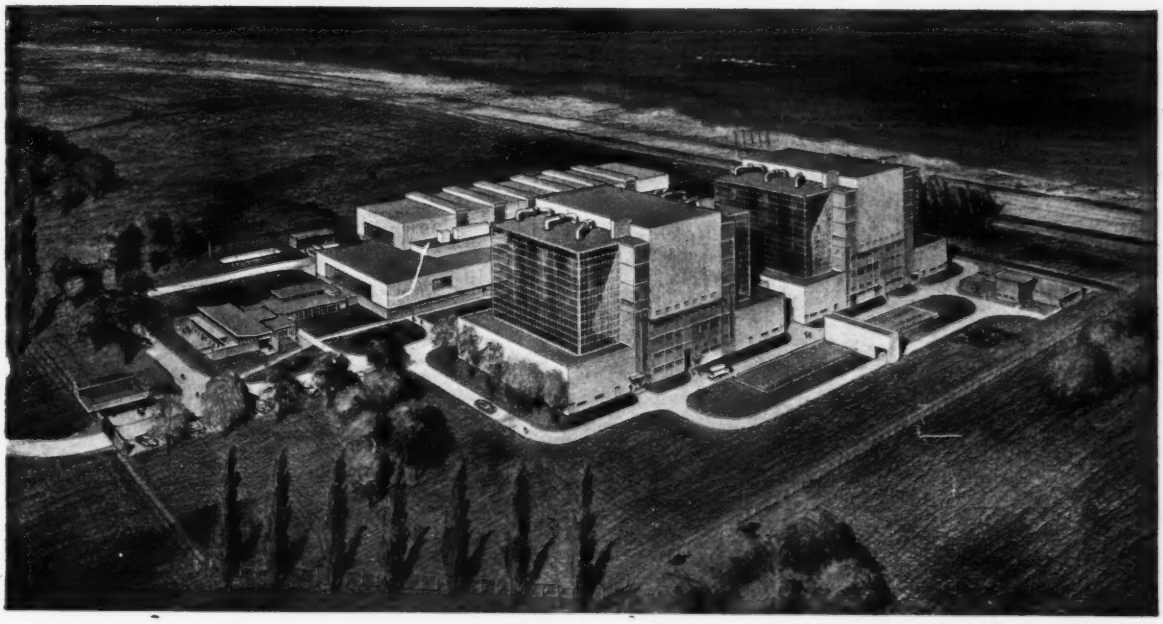
There are notable differences between the four designs in the matter of the main gas circuits. Three of the groups are using large gas ducts of approximately 5 ft. diameter with hinged bellows to give the necessary flexibility. The E.E.-B. and W.-T.W. design, however, uses a larger number of small-diameter gas ducts which are intended to provide the necessary degree of flexibility without recourse to the use of bellows. In the G.E.C.-S.C. design the main gas circulators are of the centrifugal type and are housed inside the heat-exchanger shells. In the other three designs, however, axial blowers are employed with external casings. Each group has selected a different method for driving the blowers and for providing the necessary degree of speed variation. The designs which are now offered cover a.c. induction motor drive with hydraulic fluid coupling, variable frequency three-phase motors supplied by special steam-driven turbo-alternators, d.c. motors with variable voltage supply from a special mercury-arc rectifier and transformer installation, and finally individual steam-turbine-driven blowers. Each of these different methods of driving and controlling the speed of the gas circulators may be regarded as an improvement, both in simplicity and cost, compared with

the Ward-Leonard control which was adopted for the Calder Hall reactors. The question as to which is the best method, however, can only be answered in relation to other features of the gas circuit and reactor design.

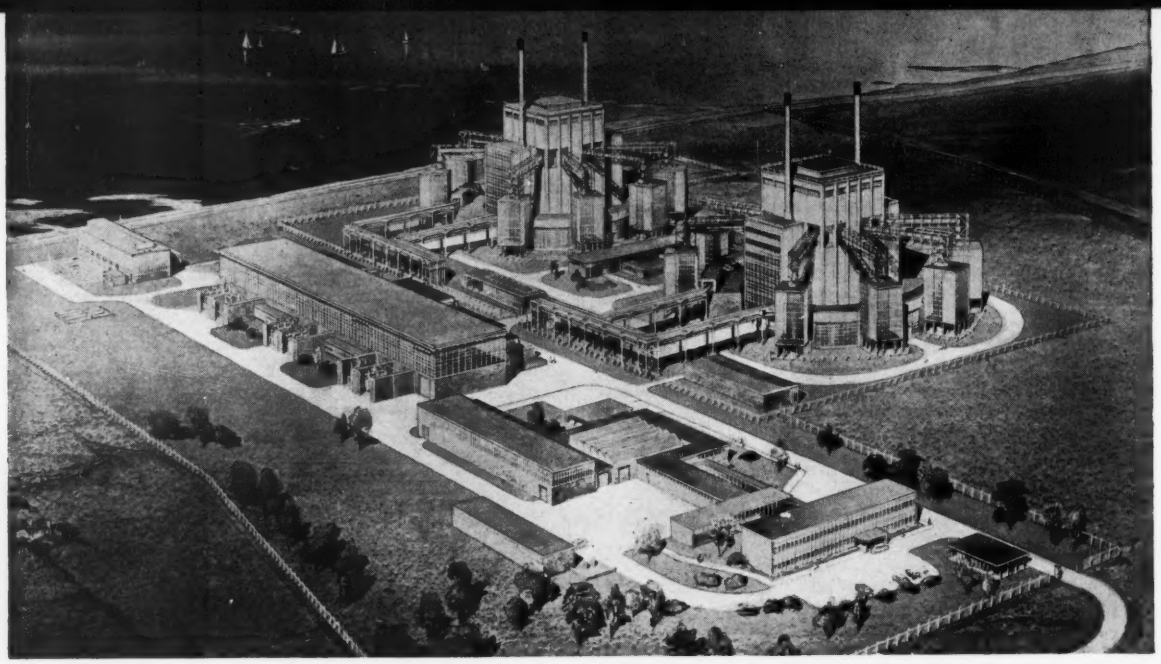
There is some variation from one scheme to another also in the number of heat exchangers and circulators used with each reactor. The A.E.I.-J.T. and G.E.C.-S.C. designs both involve the use of eight gas circuits in parallel, each circuit having a single heat exchanger and gas circulator. In the N.P.P.C. design, on the other hand, there are only six heat exchangers associated with each reactor. The E.E.-B. and W.-T.W. design differs again in having only four main gas circuits in parallel, each with a steam-turbine-driven axial-flow circulator, but with two heat exchangers per circuit and with several small-diameter gas ducts instead of the single large-diameter ducts employed both at Calder Hall and in the other designs. A special feature of the N.P.P.C. gas circuit design is the high rate of natural circulation flow which is claimed for it. This is achieved mainly by locating the heat exchangers at a higher level relative to the reactor than in some of the other designs.

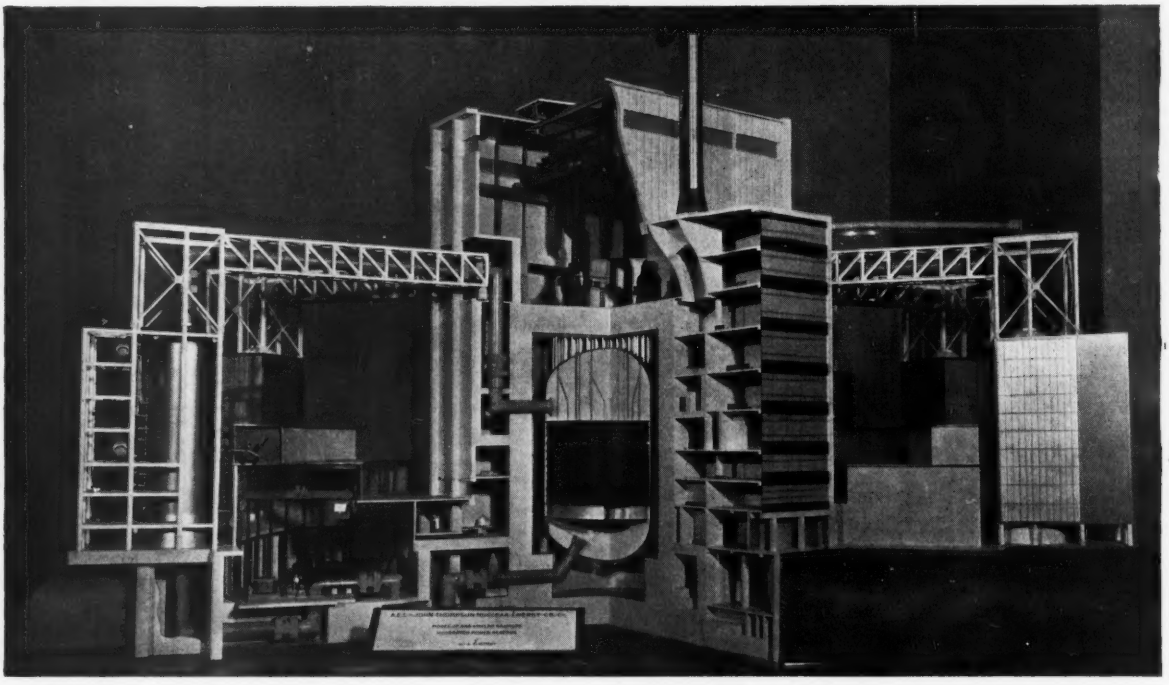
In all four schemes the double-pressure steam cycle is employed and the general features of the heat exchangers





The Bradwell station as it will appear on completion. Above: a cut-away view of a model of the Nuclear Power Plant Company's reactor system. Availability of large quantities of cooling water eliminates the necessity for cooling towers.





The A.E.I.-John Thompson design for the Berkeley station retains the principle of top charge and discharge into a cylindrical pressure vessel. The eight heat exchangers per reactor are individually sited around the main reactor building.

are not unlike those of Calder Hall, although various modified forms of extended surface are proposed for the heat-exchanger tubes. The hot-gas outlet temperature, however, ranges from approximately 650°F in one to nearly 750°F. This is partly due to different degrees of optimism or pessimism regarding the maximum permissible working temperatures for the fuel elements in the reactor, but it is also due to widely differing views on the design margins which are necessary to cover local departures from the nominal operating conditions.

There is a correspondingly wide variation in the steam conditions from one design to another. For the A.E.I.-J.T. design for the Berkeley station the steam pressures will be 306 and 62 p.s.i. and both H.P. and L.P. steam will be superheated to 612°F. In the N.P.P.C. design for the Bradwell station the steam pressures will be 755 and 195 p.s.i. with superheat in each case to 704°F. In the G.E.C.-S.C. design for the S.S.E.B. station the H.P. steam conditions are 585 p.s.i. and 700°F, and the L.P. conditions 155 p.s.i. and 670°F. These must be compared with the Calder Hall pressures of 185 and 38 p.s.i. with superheat to 526°F.

The various turbine manufacturers have prepared designs for special turbines appropriate to steam conditions in this

Station	Group	Turbo Sets	Number of Heat Exchangers per Station	Total Installed Capacity MW	Net Output MW	Steam Conditions H.P.		L.P.	
						P.s.i.	°F	p.s.i.	°F
Bradwell	N.P.P.C.	6 × 52 MW 3 × 20 MW	12	372	300	755	704	195	704
Berkeley	A.E.I.-John Thompson	4 × 80 MW	16	320	275	306	612	62	612
S.S.E.B.*	G.E.C.-Simon Carves	6 × 60 MW	16	360	300	585	700	155	670

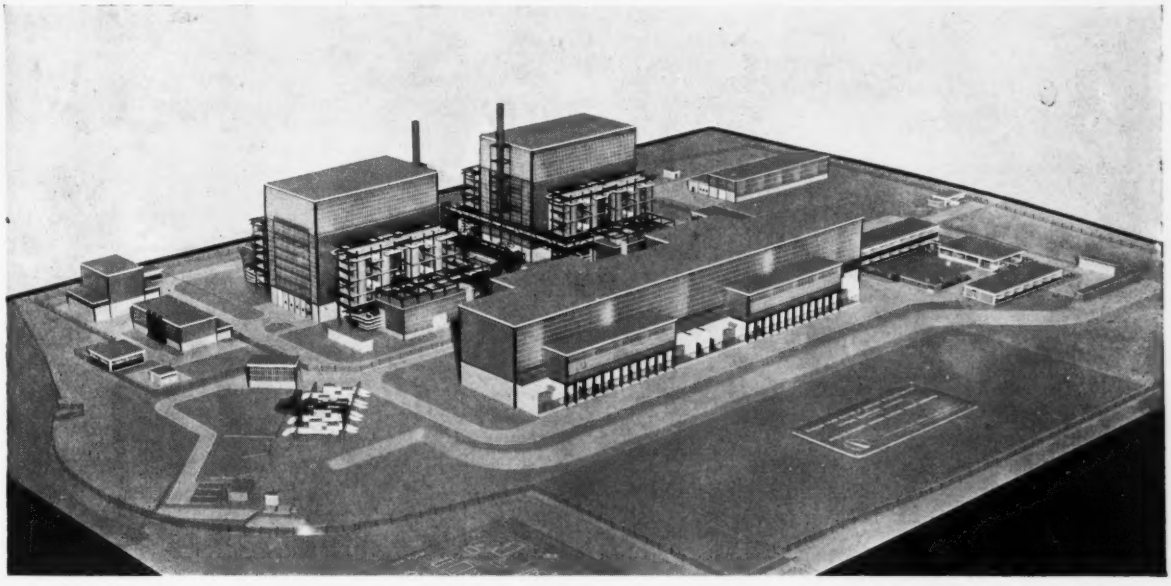
* Site not yet officially settled.

range. In general, the low-pressure end of existing 120-MW or even 200-MW sets has been taken as the basis. It is not always appreciated that the exhaust end of a machine of, say, 60 MW output designed for the moderate steam conditions that can be reached with nuclear plant will be roughly similar in size to the exhaust end of a 120-MW turbine operating on normal high-pressure steam conditions. In two of the present schemes, A.E.I.-J.T. and E.E.-B. and W.-T.W., two turbo-generators are proposed for each reactor. In the G.E.C.-S.C. and N.P.P.C. schemes, however, three turbo-generators are recommended for each reactor; it should be noted that these designs offer the largest power output, in each case approximately 150 MW net electrical output from each reactor with provision in the first for the figure to be stepped up to 160 MW.

There is some variation in the general layout of the reactors, turbine halls and associated plant. To some extent, this is occasioned by different methods which are proposed for the fabrication and construction of the plant. Two of the groups are proposing to use a large Goliath crane which will be erected on the site and will be capable of handling all the heavy lifting. It is intended in these two schemes that the Goliath crane will, after completing the main erection work on the first reactor, move on to the construction of the second reactor on the same site. For this reason, the reactors are laid out in line.

Other features of the layout, which vary to some extent, are the position of the heat exchangers and of the blower houses in relation to the reactors, and the arrangement of the cooling pond. The main features are apparent from the accompanying photographs of models. It must also be noted that the exact layout on any particular site can only be fixed in the light of the geological features, and of the arrangement of the cooling water system.

The general conclusion to be derived from a study of the four designs which have now been put forward is the extent of the advance that has been possible in power output from the relatively modest figures at Calder Hall, which were, of course, optimized for plutonium rather than for power production. It must also be remembered that the design and construction of Calder Hall was carried through in the minimum time and no one was permitted to hold up this relentless programme in any way. The ultimate development of any reactor design is, of course, determined largely by the limitations of the fuel elements. The four schemes submitted by the industrial groups all employ basically the same type of fuel element, that is to say, using uranium metal produced from the same plant at Springfields, using the same material for the can, and using essentially similar methods of fuel-element fabrication. After another year's operational experience at Calder Hall it will be possible to make a much more reliable estimate of the probable life and the permissible level of irradiation that may be achieved. In the meantime, all four of the groups are putting a considerable effort behind their own research and development programmes to improve the basic technology of their fuel-element designs. Taken in conjunction with the very large effort on fuel elements which is being undertaken by the Research and Development Branch of the U.K.A.E.A. at Risley, there can be no serious doubt that the gas-cooled, graphite-moderated will enjoy a long and successful period of development.



Model of the English Electric-Babcock and Wilcox-Taylor Woodrow station. Permission is sought for the use of a site at Hankley Point, in Somerset, for the erection of a third station for the C.E.A.

MERLIN—Medium Fluese

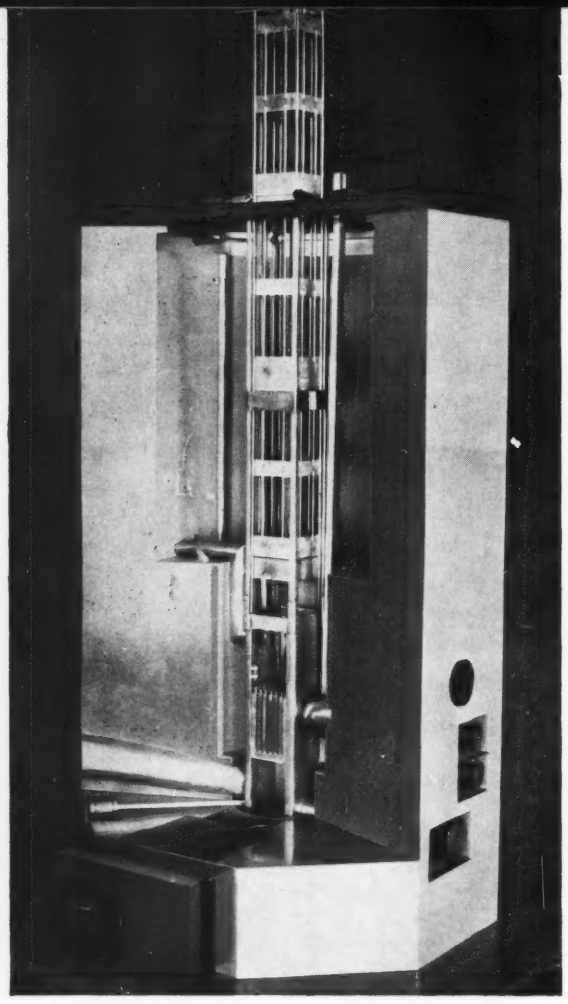


Fig. 1. Model of the MERLIN pool-type reactor.

AT the suggestion of the United Kingdom Atomic Energy Authority, Associated Electrical Industries began a design study of a medium-energy research reactor in May, 1955. A.E.I.'s interests were twofold: to provide a background of design and physics information for the A.E.I.-John Thompson Nuclear Energy Co. Ltd., and to use such a reactor as a research tool. It was decided that a medium flux research reactor sited at Aldermaston would be able to support the A.E.I. nuclear energy programme in the following ways:

(1) Relevant to Reactor Design
(a) General training and experience in reactor operation.
(b) Testing or research on instrumentation in radiation fields.
(c) Testing of materials to be used in power reactors for their neutron-absorption properties.
(d) Exponential experiments, on either solid or liquid moderators.

(2) In the Field of General Research
(i) Shielding experiments.
(ii) Fundamental work on solid-state irradiation effects.
(iii) Neutron diffraction experiments.
(iv) Neutron cross-section measurements.
(v) Activation analysis.
(vi) Chemical reactions in neutron fluxes.
(vii) Irradiation and sterilization of food and pharmaceutical products.
(viii) Production of radioactive isotopes.
Note.—The first two classifications in the general research programme are of major interest to the nuclear power programme.

An outline design for a research reactor was presented by Engineering Research and Development Division, A.E.R.E., for a power level of 100 kW with 45% enriched fuel. In July, 1955, the Authority stipulated that fuel for such research reactors would have a maximum enrichment of 20% U 235. Eventually it was decided that uranium enriched to a U 235 content of more than 90% should be made available as fuel for the reactor.

PART 1

Designed for a thermal power of 5 MW, the reactor is of the pool type, being moderated, cooled and partially shielded by light water. Fuel is a uranium-aluminium alloy, enriched to more than 90% U 235. Critical mass of the core is about 3.5 kg. U 235.

A cut-away model of the reactor is shown in Fig. 1. The main bulk of the water is in an aluminium tank which has sections, with diameters 11 ft. 6 in. and 5 ft. 6 in. The aluminium tank wall is $\frac{3}{8}$ in. thick and is surrounded by barytes concrete of density 3.5 gm/cm^3. The concrete shield is 6 ft. $1\frac{1}{2}$ in. thick for 14 ft. above floor level and 3 ft. 6 in. thick above this to the top of the shield 28 ft. above the laboratory floor. Barytes concrete is used for the first 16 ft. 6 in., thereafter the shield is made of Portland concrete.

The core can be moved to any of four positions. The top position permits the addition or withdrawal of fuel or experimental apparatus from the core. Two lower positions bring the core into the plane of two sets of experimental facilities. The lowest, or storage position, is such that the entire core is below the level of the lowest beam hole. The core is attached to a vertical aluminium framework which is hoisted by a motor situated just above the water level. The total lift is 9 ft. 3 in.: 2 ft. 3 in. between the storage and lower experimental position, 3 ft. between the two experimental positions, and a further 4 ft. to the "work on core" position.

The core is cooled by primary water which is pumped into the side of the aluminium tank. The water flows downwards through the core which is surrounded by a flume. The design is such that water cannot be removed from the core in its storage position due to leaks occurring in the experimental tubes or any of the pumping plant outside the main shield.

Water is taken out of the reactor through the shield under the main foundation to a "delay" tank. This tank volume is such that the water transit time between the core and heat exchanger is 110 sec., after which it passes to the water-purification plant.

Four reactor control units are used. Two safety units

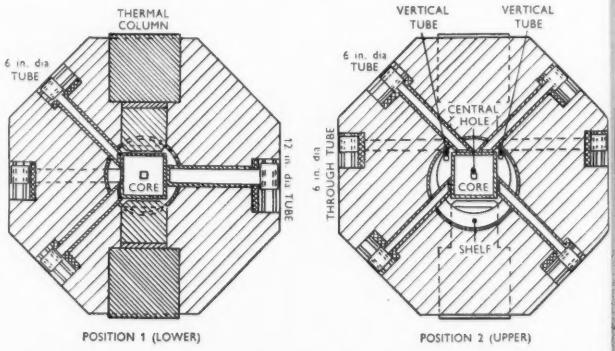


Fig. 2. Horizontal cross-sections through the reactor, showing experimental facilities.

...esearch Reactor

by

D. R. CHICK, B.Sc., F.Inst.P., and A. J. SALMON, B.Sc., Ph.D., A.Inst.P., A.M.I.E.E.

Research Laboratories, Associated Electrical Industries Ltd.

control 0.055 in reactivity each, the coarse control unit also controls 0.055, whilst the fine unit is equivalent to 0.005 in reactivity. These units are carried by rods attached to the drive motors by rack and pinion gearing giving positive drive; the coarse and safety units are in two parts, joined below water level by two magnets energized, or de-energized, by the control system. The whole assembly is fixed to the vertical structure so that it moves with the core.

An attempt has been made to provide the maximum number of irradiation facilities, Fig. 2 shows horizontal cross-sections through the reactor.

At the lower of the two core positions for experimental work the facilities are:

(1) Two horizontal graphite thermal columns 8 ft. 1 in. long and 4 ft. 6 in. square at the experimental face of shield.
(2) One horizontal 12-in. diameter beam tube.
(3) Three horizontal 6-in. diameter beam tubes.
(4) Central vertical hole in core, 3 in. × 3 in. × 24 in.

At the upper experimental position the facilities are:

(1) Central vertical hole in core, 3 in. × 3 in. × 24 in.
(2) Four horizontal 6-in. diameter beam tubes.
(3) Two horizontal 6-in. diameter tubes straight through reactor passing close to core face.
(4) Two vertical tubes, 3 in. × 6 in. section, parallel and close to core face.
(5) Shelf to take object, of maximum dimensions about 18 in. cube, up to the core face.

Physics of the Core

The fuel elements for the reactor consist of fourteen fuel plates in an open-ended aluminium box. Each plate is a uranium-aluminium alloy encased in an aluminium sheath. These plates are all dished in the same direction to minimize any effects of expansion. These are 10 grammes of U 235 in each plate; the uranium is enriched to more than 90% U 235. The thickness of the central portion in the plate is 0.018 in. and the sheath is 0.020 in. thick. The cross-sectional dimensions of the box are about $2\frac{7}{8}$ in. by $2\frac{7}{8}$ in., while the active length is about 24 in. The overall length of the fuel element, including its bottom locating spigot and top handling attachment is about 3 ft. Each fuel box will have associated with it an Sb-Be neutron source. The fuel elements can be fixed in a square lattice plate, the number of fuel-element positions is 49 in a 7 by 7 array. A side view of the core, partially filled, is shown in Fig. 3. The total number of positions available is 77, in a 9 by 9 array less the corner holes. However, fuel elements cannot be placed in the outer row of holes. This ensures that fuel cannot be placed within 4 in. of the beam tubes or thermal columns and effectively insulates the reactivity of the core from events in the beam tube and thermal columns. For example, if a 12-in. diameter beam tube were suddenly to be flooded with water with the core built against this tube the increase in reactivity would be about 5×10^{-3}; as the reactor is designed, any change in the beam holes, thermal columns or in the core position, so long as the edge holes are empty, will not produce any appreciable change in core reactivity. This is felt to be a feature adding considerably to the safety of the reactor. Preliminary estimates suggest that when solid beryllia reflector units, one row thick, are used the core mass will be small enough to ensure that the outer ring of lattice holes will not have to be used. The diminution of the thermal neutron flux in the beam holes or thermal column due to this safety feature will be negligible. However, there will be a considerable reduction in the maximum epithermal neutron flux possible in the beam holes. The γ-radiation fluxes in the beam holes will also be reduced by about 50%.

The core design is such that fuel elements can be removed from near the core centre, so that apparatus or specimens can be placed in the region of maximum radiation flux. The reactivity invested in any one experiment in the core region will be limited to a maximum of 10^{-2}.

The critical mass of the cold, unpoisoned reactor with no built-in reactivity, no central hole and an infinite water reflector, that is one about 4 in. or more thick, has been calculated. The core has been assumed to be homogeneous and two-group theory has been used. The results as a function of the mass of U 235 per litre of water are shown in Fig. 4. The central experimental hole has been allowed for as a perturbation on this system; the hole increases the critical mass with 14 plates per box by 0.14 kg of U 235. The critical mass of the cold, unpoisoned reactor, with no built-in reactivity but with a central hole, is thus estimated at 2.76 kg. Typical errors

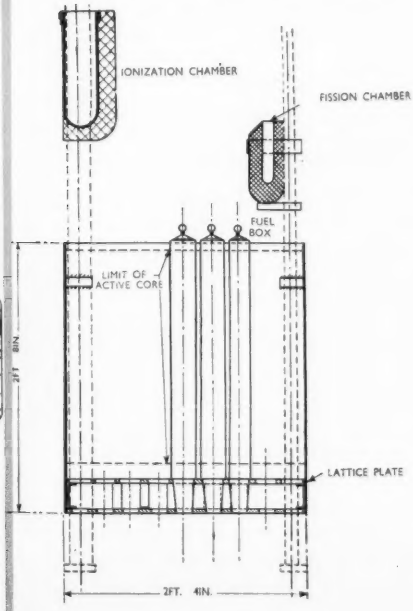


Fig. 3 (left). Side view of core, showing fuel box.

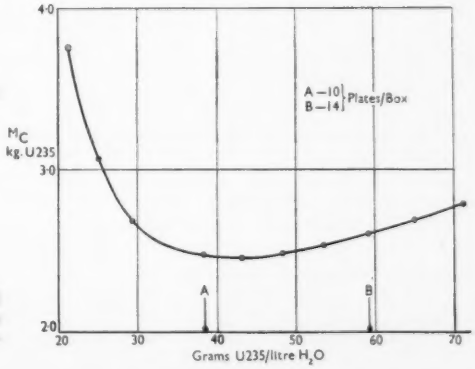


Fig. 4 (right). Critical mass plotted against ratio of grams of U 235 to litre of water, with 90% enrichment.

on calculated critical masses for light-water-cooled and moderated cores are about ± 15%.

In order to control excess reactivity as closely as possible, some of the fuel supply will be in the form of incomplete boxes. These boxes will contain one, two, four and six plates each. Combinations of such boxes will allow an addition of any number of plates up to thirteen to be made. The maximum excess reactivity on this count would then be the equivalent of 10g U 235; if such a scheme is not used, then excess reactivity equivalent to nearly 140g would be possible.

The temperature coefficient of the core reactivity has been calculated. The variation of this coefficient, α, with water temperature is shown in Fig. 5. Assuming a 20°C rise in water temperature between hot and cold states and an ambient pool temperature variation of 15°C, the total

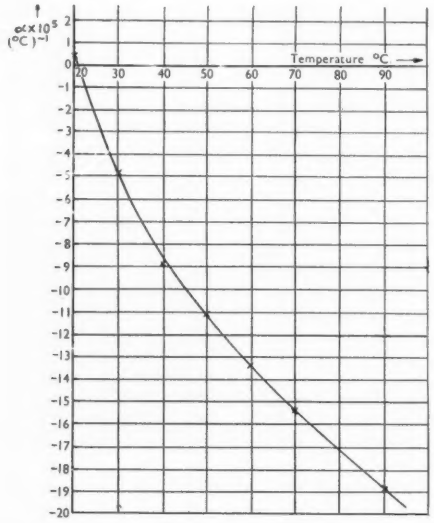


Fig. 5 (left). Variation of temperature coefficient of the core reactivity with water temperature.

Fig. 6 (right). Vertical cross-section showing the shielding arrangements.

reactivity variation due to temperature is estimated at 1.8×10^{-3}.

The total maximum built-in reactivity of the core is made up as shown in Table I.

TABLE I.

	Reactivity
Temperature	18×10^{-4}
Experimental absorbers	150×10^{-4}
Xenon, 5 MW	300×10^{-4}
Samarium, two day over-ride	10×10^{-4}
Other fission products, to 75 MWD	12×10^{-4}
Fuel burn-up, to 75 MWD	49×10^{-4}
Core over required size	10×10^{-4}
Total	549×10^{-4}

It is emphasized that this is the maximum built-in reactivity. During the initial operation of the reactor, the necessary built-in reactivity will be very much less than this. It will be normal procedure to minimize the built-in reactivity, so far as is conveniently possible, in order to ensure uniform "burning" of the fuel in the core and to reduce the possibility of large reactivity changes giving rise to power surges.

The calculated neutron lifetime in the cold, unpoisoned reactor is about 60 μsec.

The control units are of a cruciform plate structure, they are of cadmium sheathed in aluminium and control the following amounts of reactivity:

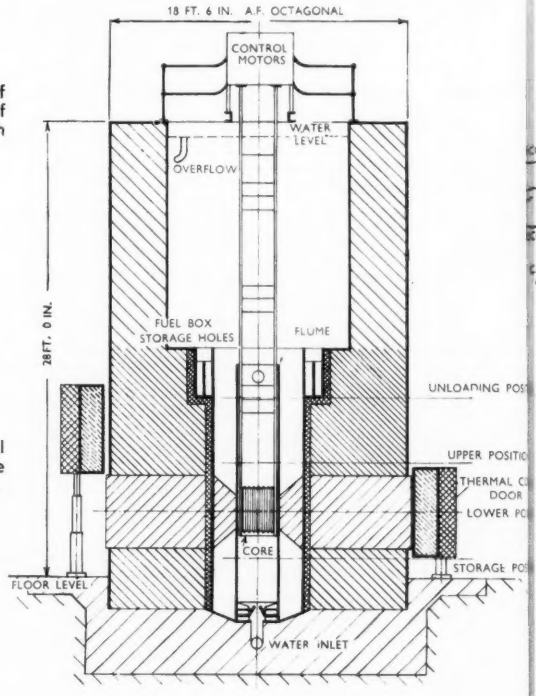
One fine control unit	50×10^{-4}
One coarse unit	550
Two safety units, each	550

Thus each safety rod and the coarse rod will separately control slightly more than the maximum built-in reactivity. The actual reactivity invested in all units will be checked in a sub-critical assembly before they are used with the reactor. This will be a separate experiment to the actual calibration of the units which will be performed in the reactor before it is operated at any appreciable power.

The sub-critical assembly will also be used to obtain experimental evidence, before the reactor becomes critical, on:

(a) minimum critical mass, cold and unpoisoned;
(b) as (a), but with a central void;
(c) effect of beam tube voids; and
(d) temperature coefficients.

The range of radiation fluxes available in the experimental facilities are given in Table II. These are calcu-



lated on the basis of a power level of 5 MW, a U 235 core content of 3.5 kg and a maximum to mean flux ratio in the core of 1.5. The actual value of any radiation flux will be proportional to the thermal power of the reactor.

TABLE II.—RADIATION FLUXES AVAILABLE AT 5 MW

Position	*Thermal neutrons*	*Epithermal neutrons*	*γ-rays*
	n/cm²-sec	n/cm²-sec	rad/hr
Core centre	5×10^{13}	2×10^{14}	4×10^{5}
Maximum in experimental holes...	10^{13}	2×10^{12}	1×10^{5}
Maximum in external beam 12-in. tube ...	2×10^{10}	4×10^{7}	2×10^{3}
Thermal columns:			
Maximum	2×10^{13}	2×10^{12}	10^{5}
Minimum	2×10^{9}	5×10^{6}	5×10^{3}

Shielding

The shielding around the reactor, see Fig. 6, is designed so that at 5 MW the radiation level in the experimental area is less than 0.1 of the normally allowed level of radiation (0.3 rad per 40-hour week). The corresponding level

of radiation directly from the core above the water surface is about 5 m.p.l. The estimated level of radiation from the N 16 γ-radiation, produced from the O 16 (n, p) N 16 reaction by fast neutrons, may possibly be high at 5 MW. Thus when the reactor is operating at 5 MW personnel may not be allowed near the top of the reactor. At 1 MW the total radiation level will be greater than 1 m.p.l., implying that a person's time spent in this region per week will be restricted. Normally when the reactor is operating personnel will not work near the top of it. It will be the responsibility of experimenters to ensure that the radiation level in the experimental area does not rise above 0.1 m.p.l. due to stray radiation from beam holes or thermal columns.

Part of the shielding (all of it in the vertical direction) is performed by the tank water. In the horizontal direction the main shielding effect is achieved by a wall of concrete. In the region of the core this concrete is of the barytes type, 6 ft. 1½ in. thick, having the specified density of 3.5 g/cm³. Between the concrete shield in this region and the aluminium tank is a layer of 4 in. of lead. The lead, acting as a thermal shield, protects the concrete from the radiations emitted by the core. The maximum energy flow into this shield in the form of radiation is of the order of 500 W/ft.². If this amount of energy were all allowed to pass into the concrete, the thermal stress produced would result in cracking of the concrete. This lead thermal shield has aluminium tubing embedded in it through which water may be circulated, if necessary, to cool the lead.

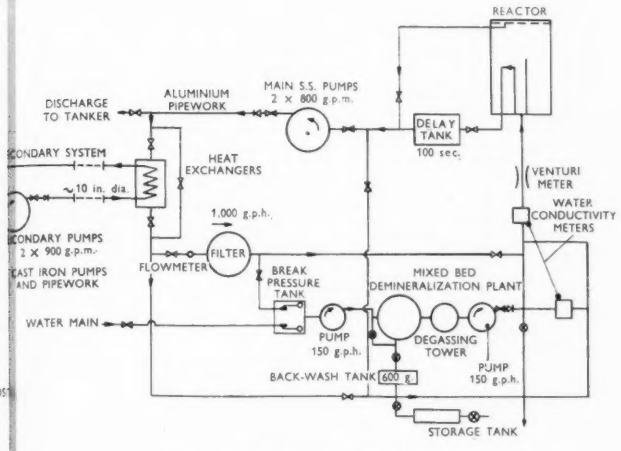


Fig. 7. Flow diagram of the water system.

The use of heavy concrete in the lower part of the shield enables the shield to be thinner than would be necessary with ordinary concrete. The upper part of the shield, which is further removed from the core and, in addition, is partially shielded by the lower shield, is of ordinary Portland concrete 3 ft. 6 in. thick. The density of this concrete is specified as 2.3 g/cm³.

The reduction obtained in the thickness of the shield allows the whole dimension across the top of the reactor to be reduced. This has the effect of allowing experiments outside the reactor to be placed nearer to the core and thus in a higher radiation flux. The smaller size of reactor enables a smaller foundation raft to be used and allows rather more room round the reactor for a given size of building. However, the barytes concrete is more expensive than the Portland concrete, approximately a factor of × 2 per unit mass.

A disposal area for the core elements and activated experimental apparatus will be available. This is designed so that a total of 64 fuel boxes can be accommodated after an irradiation of 100 days at 5 MW. The fuel boxes are stored in the reactor tank for the first five days after irradiation.

Thirty-six reflector elements can also be stored following an irradiation of 100 days at 5 MW; in this case the beryllia elements are stored for the first ten days in the reactor tank. At the same time, the disposal area can accommodate 250 curies of experimental apparatus, assuming that each disintegration produces one 3 MeV γ-ray.

The level of radiation in this area will be about 1 m.p.l. when it is fully loaded.

Fixed radiation monitoring for γ-radiation and thermal neutrons will be incorporated in the reactor building and periodic checks of the reactor area will be made with γ-ray and fast neutron hand monitors. Three γ-ray and two thermal neutron detectors will be sited in the experimental area, one γ-ray monitor will be above the pool, in the water plant area there will be two γ-ray monitors and a fission product detector; there are to be two γ-radiation monitors in the storage building. The monitors in the experimental area are so arranged that if any of them read tolerance level a danger alarm is given on the control desk and local action is taken. If any one instrument gives a × 10 tolerance indication, a virtually continuous warning is given until the high flux is reduced locally, or the reactor operator reduces the power level.

The Water System

The water in the reactor performs the triple function of moderating, cooling and partially shielding the core.

Fig. 7 is a diagrammatic arrangement of the water system. In the main circuit the water is drawn through a pipe in the side of the square-section flume above the core and returned through a valve at the bottom of the flume for passage through the external circuits. In case of failure of the main circulation, this valve is arranged to uncover ports in the flume wall so that circulation by natural convection through the core can take place.

Water coming from the reactor passes through a 100-second delay tank to allow decay of induced radioactivity in the water (N 16, half-life 7.3 sec.) before entering the pumps and heat exchangers. A radiation monitor is provided at entry to the plant house to detect any increase of activity in the primary water.

The water flow in the main circuit is metered and arrangements are made so that the reactor will shut-down if the flow is outside the required limits. There are similar arrangements with regard to water level in the tank and water temperature.

The system is designed to require one 800 g.p.m. pump for operation up to 1 MW and two pumps in parallel from 1 MW to 5 MW. This gives a temperature rise of 10°C in passing through the core, the estimated maximum water temperature being 45°C. The pumps are of stainless steel where they come into contact with the water; the primary pipes are of aluminium.

The secondary circuit, which draws water from Aldermaston lake, cools the water of the primary circuit in four vertical shell and tube heat exchangers. One pump is in service, providing 900 g.p.m. up to 1 MW and two pumps for operation above 1 MW. A radiation monitor at the output of the heat exchanger, on the secondary circuit side, will sound an alarm and stop the pumps if undue activity is observed.

A by-pass system on the main primary circuit provides for the maintenance of the water purity. Approximately

1,000 g.p.h. is withdrawn from the main circuit through a filter. 150 g.p.h. of this water then passes through a float valve to an open tank, from which it is pumped through a mixed-bed ion-exchange demineralization plant and degassing tower and back into the main system. The remainder of the filtered water is fed straight back into the main circuit. A water conductivity meter indicates the purity of the water in the system and a similar instrument fitted at the outlet from the ion-exchange plant measures the effectiveness of this plant and indicates when regeneration of the bed is necessary.

Filling of the system is effected from the fresh-water main via a break pressure tank from which it is pumped into the system through another mixed-bed ion-exchange plant. This latter plant also provides make-up water.

Draining of the system is accomplished through what is normally the water outlet of the reactor, and discharging through a branch pipe to tanker or waste.

TABLE III—TYPICAL ANALYSIS OF WATER IN MAIN TANK

	p.p.m		p.p.m.		p.p.m.
Aluminium ...	0.05	Zinc	0.02	Cobalt ...	<0.1
Boron ...	<0.01	Sodium ...	0.5	Manganese ...	<0.1
Copper ...	<0.01	Potassium ...	0.1	Indium ...	<0.1
Lithium ...	0.02	Magnesium ...	<0.1	Chlorides ...	<0.5
Calcium ...	0.05	Silver	<0.2	Nitrates ...	<0.5
Cadmium ...	<0.01	Iron	<0.1	Silica	5-10
Chromium ...	0.05	Nickel	<0.1	Carbon Dioxide	5
				pH	μ~6

The Reactor Building

An experimental area extending 22 ft. back from the faces of the reactor shield is provided. This is enclosed by a sixteen-sided brick building extending to a ceiling height of 15 ft. Above this height the reactor is enclosed by a tower extending to an inside height of 50 ft. above floor level. A covered way extends radially from this tower to allow a 10-ton travelling crane to traverse from the reactor to a lorry-unloading bay outside the building. The floor of this extension is formed by a platform level with the top of the reactor, access to which is by a staircase from the main experimental floor.

Two doorways are provided to the experimental area. One is for goods access and is 10 ft. wide by 14 ft. high; this may be clamped shut to be almost air-tight. Two double swing doors in series are provided for personnel access, giving the minimum entry of dirty air from outside. On each side of the personnel door are rooms from which windows overlook the experimental area. One of these is the control room for the reactor; the other serves as an observation and conference room.

In order to ensure that the reactor building will provide some containment of any release of radioactivity, it is being designed so that none of the windows can be opened. Ventilation within the building is good with the exhaust passed out to atmosphere through a chimney stack rising above the topmost part of the reactor building. A filter system is provided through which all exhausts are passed. These are shown in Table IV.

TABLE IV.

	Above Pool	*Beam Tubes*	*Main Building*
Flow	1,000 cu. ft.	1,000 cu. ft.	7,000 cu. ft./min.
Possible activity or other substance to be removed.	N16, also hydrogen. Fission products in case of accident.	A 41 and radioactive dust.	A 41. Fission products or activity from experiment in case of accident.

These systems scavenge the region above the pool of hydrogen and radioactive gases, change the air in the beam holes at the rate of five times per minute to maintain tolerable the air activity and change the air in the main building five times each hour. This main filter has a specification of 99% efficiency for particle sizes down to 1.0 μ diameter. In the event of the release of fission products from the reactor effectively 93% may be absorbed by the filter and 7%, being gaseous, will pass on to the stack. A monitor at the base of the stack makes possible observation that a satisfactory level of activity is released to atmosphere.

The air flowing into the building is also filtered; these filters have to be about 90% efficient at 1 μ diameter.

MERLIN—1ère Partie

Le Merlin est un réacteur de recherches universel conçu pour une puissance thermique maximum de 5 MW; il appartient au genre dit "pool", et il est modéré, refroidi et partiellement protégé par de l'eau légère. L'eau de refroidissement primaire doit être déminéralisée, et à pleine puissance la hausse de température de cette eau au passage par le noyau du réacteur est de 10°C. Ce réfrigérant primaire, à une température de sortie de 45°C, est fait passer par un échangeur de chaleur qui est refroidi au moyen d'un système d'eau secondaire ouvert. Le combustible est un alliage d'uranium-aluminium, revêtu de plaques d'aluminium. L'uranium est enrichi à plus de 90% d'U 235, et on calcule la masse critique du noyau à environ 3,5 kg d'U 235.

La commande du réacteur est effectuée par l'intermédiare de plaques de cadmium revêtues d'aluminium. La section de ces plaques est en forme de croix et les plaques sont commandées par un système de servo-moteur. Le système de contrôle maintiendra la puissance du réacteur constante à ± 1%, et il est très strictement entrecroisé pour empêcher le mauvais actionnement du réacteur.

MERLIN—Teil 1

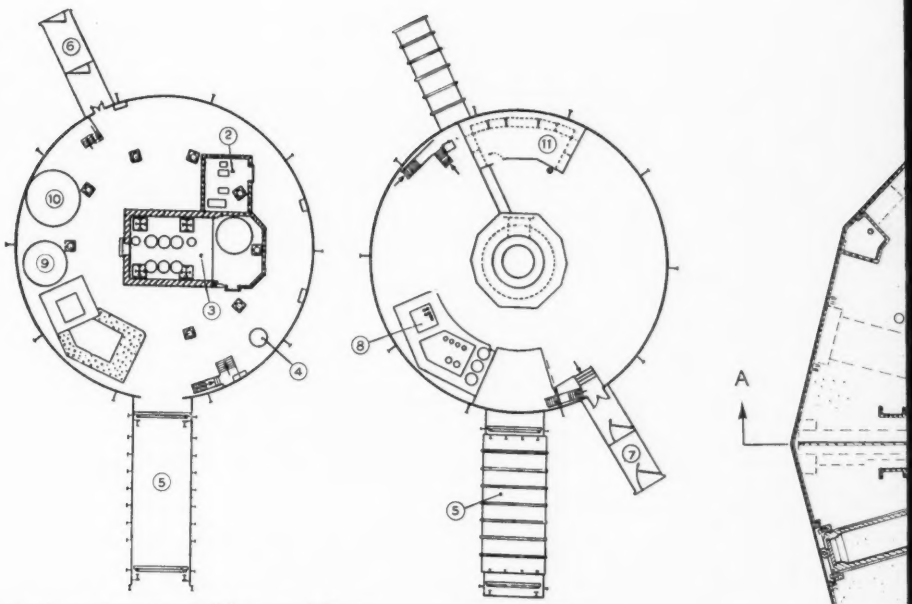
Merlin ist ein vielseitig verwendbarer Forschungs Reaktor, der für eine maximale thermische Leistung von 5 MW entworfen ist. Er gehört zur sogenannten "Pool (Tümpel)" Type, da als Brennstoff, Kühlmittel und teilweise auch als Schutzschicht leichtes Wasser verwendet wird. Das Kühlwasser im Primärkreis muss von Mineralien befreit werden; bei Vollast steigt die Temperatur des Wassers, das durch den Kern des Reaktors fliesst, um 10°C. Dieses Primärkreis Wasser hat eine Austritts Temperatur von 45°C und geht dann durch einen Wärme Austauscher, der mit einem offenen Kühlwasser-Umlauf arbeitet. Als Brennstoff dient eine Uran-Aluminium Legierung, die zwischen Aluminium Platten als Hülle angeordnet ist. Das Uran wird auf über 90% U 235 angereichert; die kritische Masse des Kerns wird auf 3,5 kg U 235 geschätzt.

Der Reaktor wird mittels Cadmium Platten, die in einer Aluminium-Hülse sitzen, reguliert. Diese Platten haben einen kreuzförmigen Querschnitt und werden mit Hilfe eines Servo-motor Systems gesteuert. Das System der Regulierung wird die Leistung des Reaktors bis auf ± 1% konstant erhalten; es ist bis auf's kleinste ineinander verriegelt, um jeden Betriebsfehler im Reaktor unmöglich zu machen.

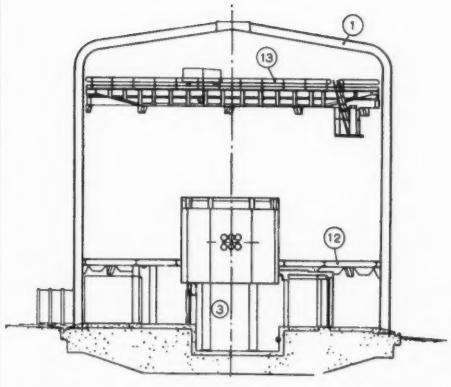
MERLIN—Parte 1

Merlin es un reactor multi-propósito de investigaciones diseñado para una potencia térmica máxima de 5 MW. Es del así llamado tipo "pool", siendo moderado, enfriado y parcialmente protegido por agua liviana. El agua de enfriamiento primario ha de ser desmineralizada, y a plena potencia la elevación de temperatura de esta agua, al pasar por el núcleo del reactor, es de 10°C. Este refrigerante primario, a una temperatura de salida de 45°C se pasa a un cambiador de calor, el que se enfría por medio de un sistema abierto de agua secundaria. El combustible es una aleación de uranio-aluminio, protegido entre planchas de aluminio. El uranio es enriquecido a más del 90% U 235, calculándose la masa crítica del núcleo en aproximadente 3,5 kg de U 235.

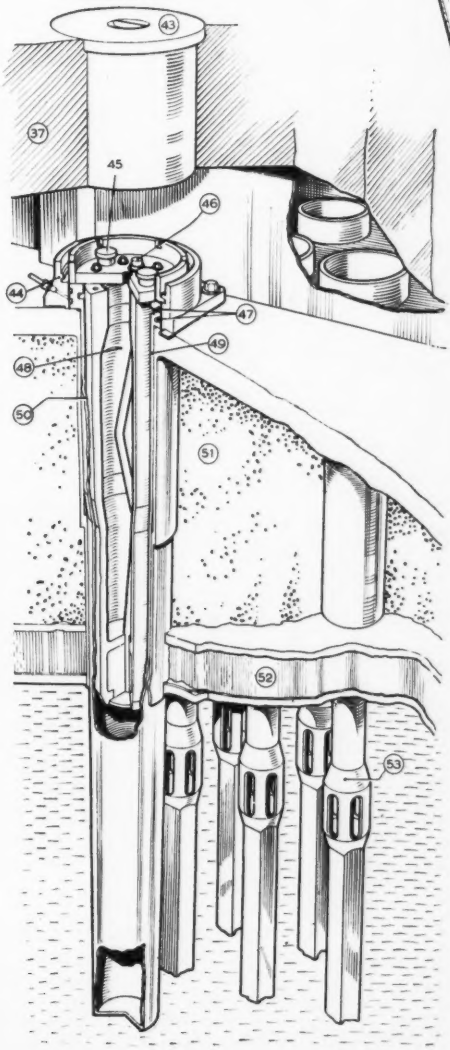
El control del reactor es por medio de planchas de cadmio protegido en aluminio. Estas planchas son de sección cruciforme y se controlan por un sistema de servo-motor. El sistema de control mantendrá la potencia del reactor constante a ± 1%, siendo estrictamente entreclavado para evitar mala operacion del reactor.



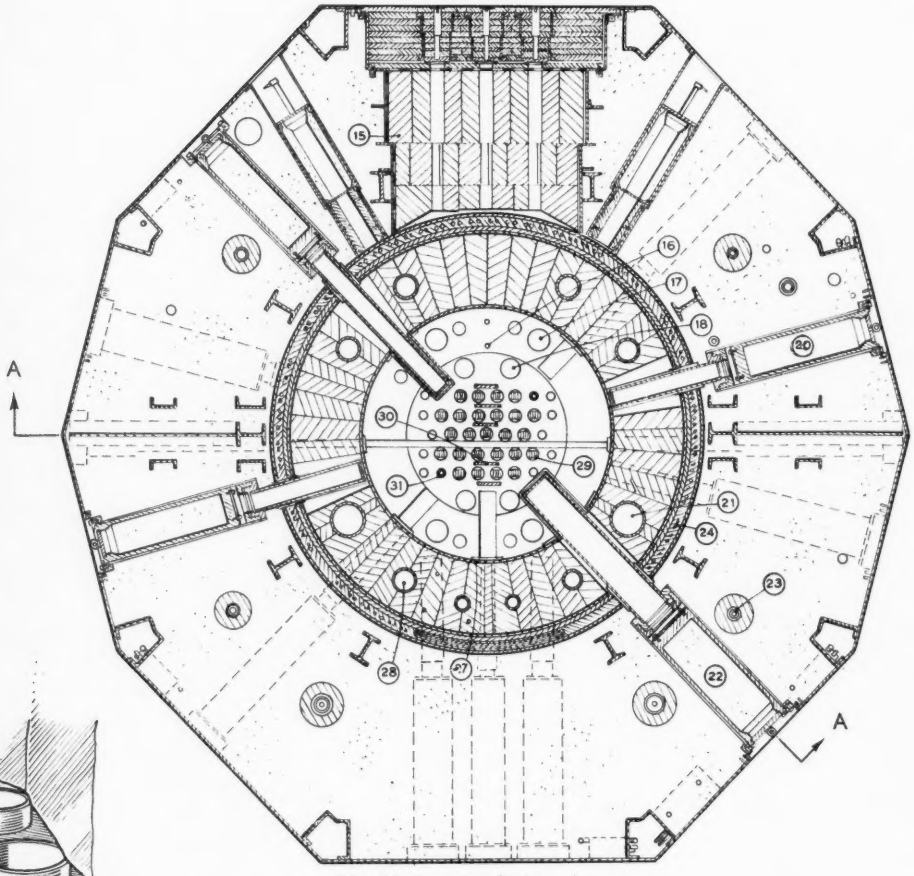
Block plans of reactor building: on left, at ground level; on right, at operating floor level.



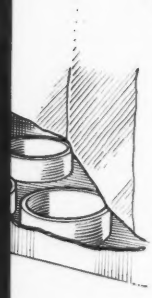
Simplified sectional elevation of building.

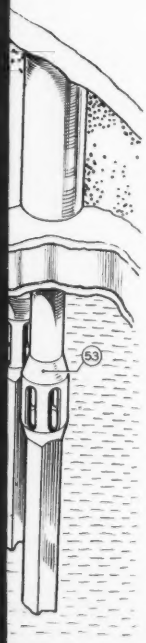


Arrangement of vertical experimental facility. *Note — The fuel elements must be regarded as diagrammatic only; the exit port arrangements have been modified.*



Simplified sectional plan of reactor.



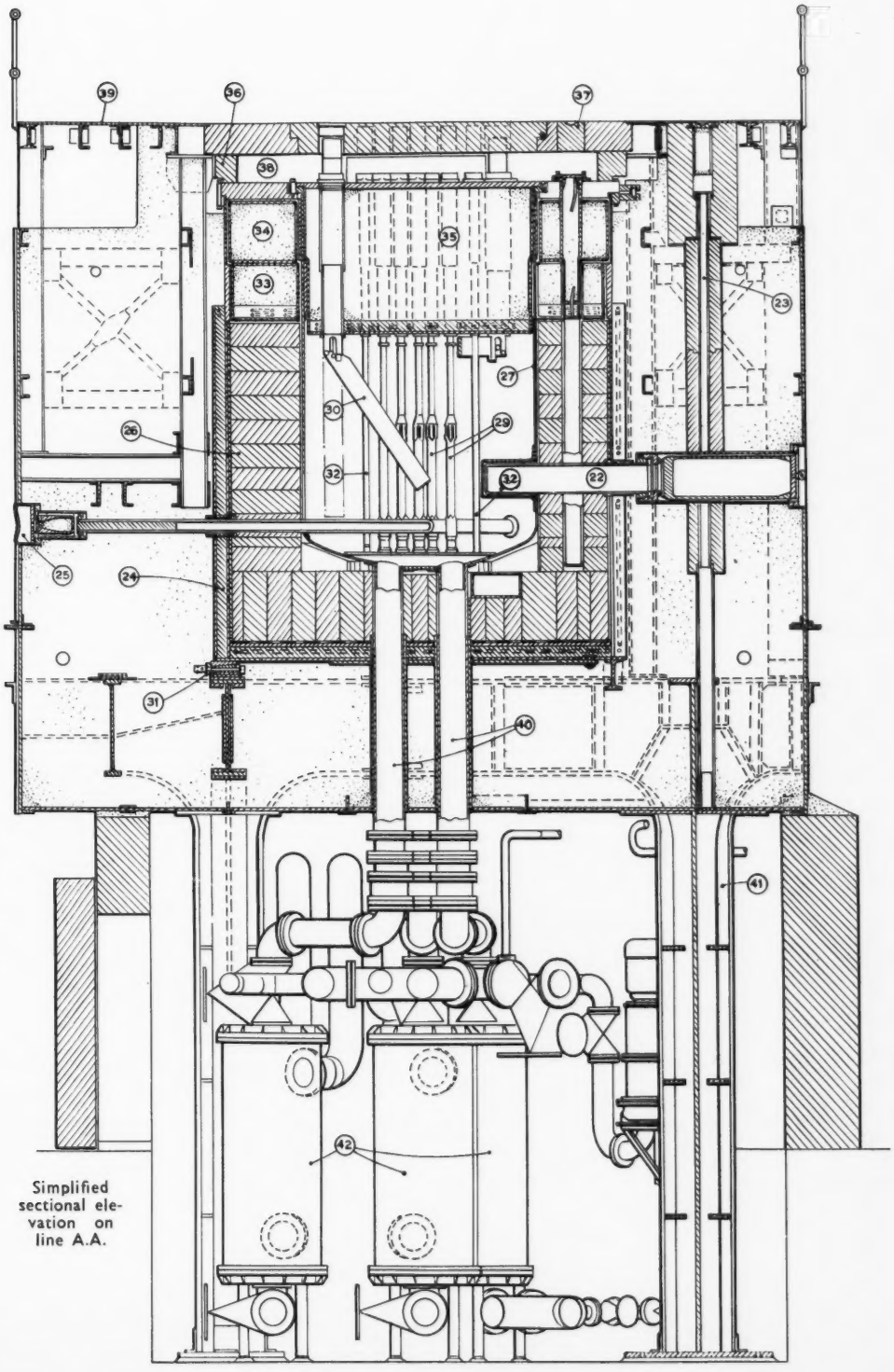


KEY

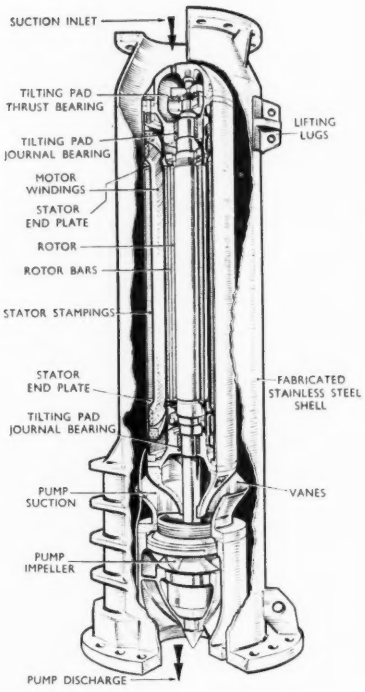
1. Steel building
2. Shield cooling water pumps
3. Heavy-water plant room
4. Helium gasholder (100 cu. ft.)
5. Vehicle air lock
6. Emergency exit
7. Personnel air lock
8. Fuel-element storage block
9. Helium gasholder (500 cu. ft.)
10. Expansion vessel
11. Control room
12. Working floor
13. Rotary crane
14. Steel diaphragm
15. Thermal column
16. 1-in. heavy-water overflow pipe
17. 7-in. heavy-water outlet pipe
18. 6-in. vertical facility in heavy water
20. 6-in. horizontal facility in graphite
21. 10-in. vertical facility
22. 10-in. horizontal facility in heavy water
23. 2-in. mortuary hole
24. Double steel tank with water-cooled lead shield and boral lining
25. 4-in. × 2-in. oval horizontal facility going right through the reactor
26. Graphite reflector
27. Aluminium tank
28. 6-in. vertical facility in graphite
29. Fuel elements
30. Coarse control "signal arms"
31. Wedge for tank levelling
32. 2-in. vertical facility
33. Lower annular shield
34. Upper annular shield
35. Top shield
36. Cast-iron ring
37. Reactor top plate
38. Void for pipes and cables
39. Floor plating
40. Heavy-water inlet
41. Main cruciform stanchions
42. Heavy-water heat exchangers
43. Removable plug
44. Adaptor
45. Locking control
46. Purge connector
47. Sealing rings
48. Concrete filling for plug
49. Aluminium liner tube
50. Stainless-steel liner tube
51. Concrete biological shield
52. Lead shield
53. Fuel elements (Note: design has been changed)

The World's Reactors

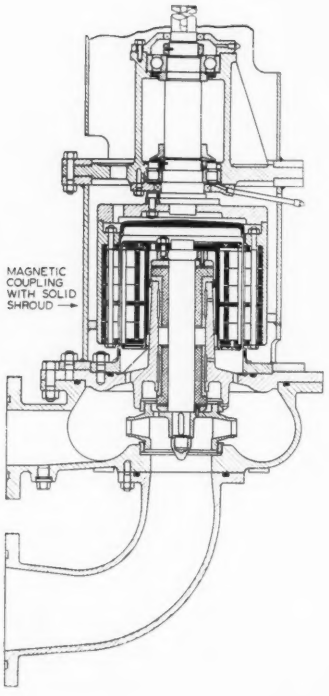
No. 8 — DIDO



Simplified sectional elevation on line A.A.



(Above) Sectional view of Hayward-Tyler main heavy-water pump, showing drowned motor construction.



(Left) Section of H.M.D. stand-by heavy-water pump, showing magnetic coupling with solid shroud.

DIDO: EXPERIMENTAL FACILITIES

General Description	Dimensions	Number
Fixed horizontal round tubes:		
(a) entering D_2O reflector	10 in. diam.	1
	6 in.	1
	4 in.	6
(b) entering graphite reflector only	6 in.	10
Fixed, horizontal oval tube passing right through D_2O reflector	4 in. × 2 in.	1
Removable, vertical round tubes:		
(a) entering D_2O reflector	6 in.	4
	4 in.	5
	2 in.	9
(b) entering graphite reflector only ...	6 in.	6
	4 in.	5
	10 in.	2
Fixed horizontal rectangular tube passing right through bottom graphite reflector	8 in. × 12 in	2
Thermal column of graphite containing square holes	5 ft. × 5 ft.	1
	4 in. × 4 in.	9

The World's Reactors—No. 8

DIDO — D(i)DO

TYPE: Thermal heterogeneous.

PURPOSE: High flux testing.
Production of radio-isotopes.

LOCATION: A.E.R.E., Harwell, England.

OPERATION: Official opening, November 21, 1956.

FUEL: Enriched uranium alloy, box type.
Alloy: uranium-aluminium, aluminium clad.
Plate form: 23.6 in. × 2.36 in. × 0.036 in.
Curvature: on radius, 5½ in.
Assembly: 2.9 in. sq. approx., nine plates per box.
Total investment: 2½ kg.

CLADDING: Aluminium: SIC.
Treatment: Aluminium sheet, welded on three sides, rolled.

MODERATOR: Heavy water.
Total investment: 10 tons.

CORE: Reacting core: 34 in. × 28 in. × 24 in. high.
Core tank: 99.8% purity Al., 6 ft. 7 in. diameter.
Lattice: basically square, central row displaced, 6-in. pitch.
Number of fuel elements: 25.

REFLECTOR: Graphite.
Segmental blocks, lead bound.
Radial thickness: 24 in.

COOLANT: Heavy water.
Flow rate through elements: 11.7 ft./sec.

FLUX: Maximum thermal neutron flux: 10^{11} n/cm^2-sec.

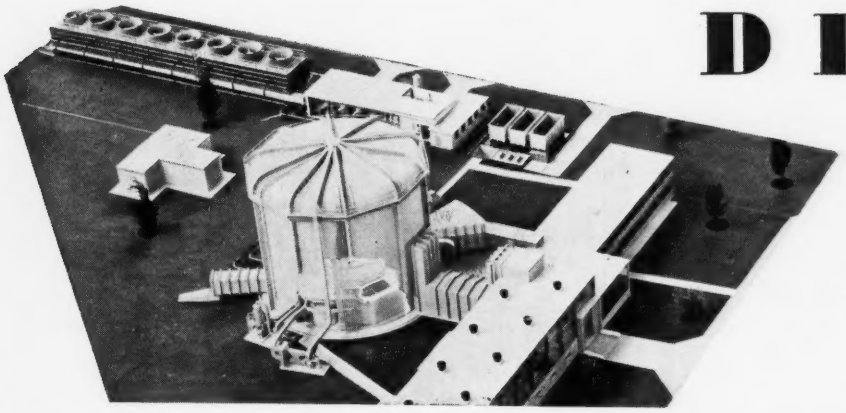
CONTROL: Coarse control/shut-off: six in number.
Construction: 0.080-in.-thick cadmium sheet, welded between 20 S.W.G. stainless-steel sheet.
Signal arm: 4 ft. 10 in. long.
Fine control rod: one in number.
Construction: 24 in. long, 255 cm.^{2}, cylinder contained between two stainless-steel tubes.
Safety rods: two in number.
Construction: Stainless-steel tube containing 990-cm.^{2} cadmium cylinder, 30 in. long.

SHIELDING: Top: Inner: 2 mm, 4 in. water-cooled lead.
Intermediate: concrete.
Outer: cast iron and steel.
Side and bottom:
Inner: boral plates.
Intermediate: steel tank, 10 ft. 10½ in. I.D. × 13 ft. 2 in. high, skin thickness ⅝ in., 1½-in. bottom plate, 4 in. water-cooled lead between skins.
Outer: Barytes concrete, 5 ft. thick.

OVERALL SIZE: Ten-sided prism 22 ft. across flats; height 17 ft. from operating floor, 32 ft. from lower floor.

OUTER SHELL: Steel building, 70 ft. diameter, pressurized at ⅛ in. W.G. below atmosphere.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).



DIDO

The Engineering Aspects

A BRIEF account of Harwell's new DIDO reactor has already appeared in these pages (*Nuclear Engineering*, December, 1956) and its objects and general characteristics have been widely publicized. From the physicist's point of view, DIDO is an enriched-uranium heavy-water-moderated reactor whose flux (10^{14}n/cm^2-sec) at a thermal output of 10 MW is the highest in Europe and whose extensive experimental facilities will permit much essential research to be speeded-up, as well as providing large quantities of isotopes of higher specific activities than have hitherto been available.

Quite apart from the physicist's point of view, however, DIDO is an intensely interesting example of an engineering project—a project as complex as a power station where familiar apparatus must be modified to meet unfamiliar conditions and where the emphasis is on quality, where nothing second-class can possibly be contemplated.

Core

The core of the reactor consists of 25 enriched-uranium fuel elements arranged as an approximate cylinder in rows of 4, 6, 5, 6, 4. Each element is made up of nine curved plates approximately $2\frac{3}{8}$ in. wide, made of a uranium-aluminium alloy clad in aluminium, the manufacture being carried out by Marston Excelsior Ltd. The plates are curved across the width to an approximate radius of $5\frac{1}{2}$ in. and are housed in an aluminium box of square section, so that the curvature is in the same direction and any uneven expansion will not cause alteration or closing-up of the gaps between plates and interfere with the even flow of coolant. At the lower end the square section becomes circular, so that the elements fit into holes or nozzles in what is, in effect, a false bottom to the tank, forming a plenum chamber or manifold for the coolant. Above the square box section there is a circular extension (with outlet ports for the coolant) and a shield plug. The box section portion, i.e., the fuel element proper, is about 2 ft. in length; the overall length of the unit is 5 ft. 8 in.

The joint between the bottom end of the fuel box and the nozzle in the plenum chamber is secured by the weight of the element and its associated shielding plug. A gas-tight seal in the form of a double "O" ring of neoprene is provided at the top of the unit. At the upper end of the plug liner is a breech-block type of quick-acting lock. This enables the element to expand longitudinally, but prevents it lifting and venting the reactor in case of an excursion causing steam. The shield plugs were manufactured by Savage and Parsons Ltd.

The control and safety gear for this core is the subject of a separate article in this issue.

Reactor Structure

Around the core in concentric layers are the heavy-water reflector; the wall of the aluminium tank; the graphite; a thin lead skin to bond the graphite to the tank lining; the boral lining; steel; lead; steel; and concrete, the whole forming a ten-sided prism some 22 ft. across the flats and just over 17 ft. from the operating floor to the upper guard rail, the overall height from the lower floor being about 32 ft. and from the sump level some 38 ft.

The details of this structure, which was built to exceedingly small tolerances, can be gathered from the accompanying illustrations showing sections of the reactor and photographs taken during construction.

The main steelwork, which carries the entire weight, was fabricated by Wright, Anderson and Co. Ltd. and is of exceptionally heavy construction, the four main legs being of built-up cruciform section 24 in. square, while some of the I-beams forming the cross-members are 2 ft. 9 in. deep.

Steel Tank

The main steel tank, which, in addition to forming an important part of the mechanical construction, would also serve to contain the heavy water in case of damage to the aluminium tank, is really a double-skinned structure. Manufactured by M. and W. Grazebrook Ltd, of Dudley, it is 10 ft. $10\frac{1}{2}$ in. internal diameter and 13 ft. 2 in. high. The concentric skins are each $\frac{5}{8}$ in. thick, the bottom plate being $1\frac{1}{2}$ in. In between these tanks is a 4-in. space filled with lead, into which are cast copper cooling coils, the coils being duplicated, so that in the unlikely event of trouble the second set could be coupled up. This tank assembly, with its lead interleaving, was the heaviest single piece of equipment in the complete project and weighed 64 tons. It is supported from the main steel structure on stools and adjusting wedges.

Riveted to the inside of the tank is a lining of boral. This, as originally used at Oak Ridge, consists of a sandwich of two aluminium plates, between which is a sheet of aluminium containing a dispersion of boron carbide (*Nuclear Engineering*, September, 1956, p. 260). The particular alloy used in this case was manufactured by Hawker-Siddeley Aircraft Co. Ltd. and may differ slightly in composition. Inside the boral lining is the graphite, lead being poured between to ensure good thermal contact. The graphite is 24 in. thick radially and at the bottom, the radial thickness being laid in the form of segmental blocks.

Illustration at top of page is a view of a scale model of DIDO, with the active handling bay in the foreground. Behind the main shell are, left to right, the cooling towers, the pump-house and the water-softening plant.

Les Aspects Techniques du Réacteur DIDO

Un compte-rendu succinct de ce réacteur, lequel par suite de sa forte puissance (10 MW) et de sa densité de flux de 10^{14} n/cm²-sec. est censé être le plus puissant d'Europe, aborde le sujet du point de vue de la technique.

Le DIDO est un réacteur à l'uranium enrichi, modéré à l'eau lourde, et l'article traite de la construction générale de l'installation entière, y compris le réservoir en acier double, le réservoir intérieur en aluminium, la protection et les divers circuits d'opération, y compris l'eau lourde, l'eau légère et l'hélium. La construction du bâtiment lui-même et la disposition des lieux figurent aussi dans l'article ainsi que les précautions prises du point de vue de la sécurité, s'étendant du nettoyage des trous expérimentaux par le gaz carbonique aux mesures prises pour l'évacuation, la recirculation de l'air et le lavage par voie humide, ainsi que le lavage des murs au cas où il se produirait une très peu probable excursion du réacteur.

Der Reaktor DIDO vom technischen Standpunkt aus

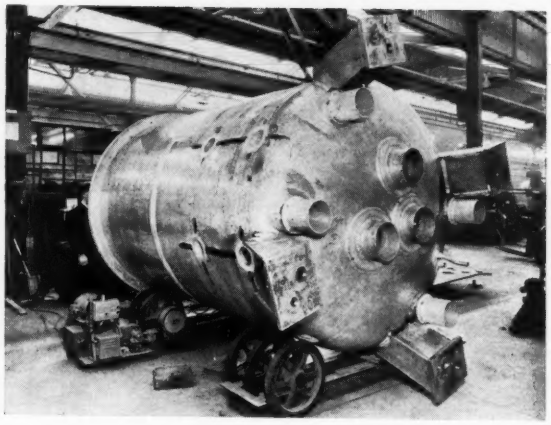
Ueber diesen Reaktor, der mit seiner hohen Leistung (10 MW) und seinem Neutronenfluss von 10^{14}n/cm²-sec wahrscheinlich der leistungsfähigste Reaktor in Europa ist, wird ein kurzer Bericht vom Standpunkt der Konstruktion aus gegeben.

DIDO ist ein mit angereichertem Uran und mit schwerem Wasser als Brennstoff arbeitender Reaktor. Der Aufsatz behandelt den allgemeinen Aufbau der gesamten Anlage, d.h. den doppelten Stahl Behälter, den inneren Aluminium Behälter, die Schutzwandungen und die verschiedenen Arbeits-Kreise, die schweres Wasser, leichtes Wasser und Helium in Umlauf bringen. Die Konstruktion des eigentlichen Bauwerks und die Einteilung des Geländes werden besprochen, und ferner die Massnahmen, die zum Zwecke des sicheren Betriebs getroffen werden müssen, von der Reinigung der Versuchslöcher mittels Kohlensäure an bis zu den Einrichtungen für Entleerung, Zirkulation frischer Luft und Reinigung der Luft, schliesslich dem Waschen der Wände in dem unwahrscheinlichen Falle einer Abscheidung aus dem Reaktor.

Aspecto Ingenieril del Reactor DIDO

Una breve reseña de este reactor el que, con su elevada potencia (10 MW) y su densidad de flujo de 10^{14} n/cm²-seg. se estima sea el más potente en Europa, trata del asunto desde el punto de vista ingenieril.

DIDO es un reactor moderado con agua pesada y enriquecido con uranio, y el artículo trata de la construcción general de la instalación entera, incluyendo el tanque doble de acero, el tanque interior de aluminio, el blindaje protector y los diversos circuitos operadores, incluyendo agua pesada, agua liviana y helio. La construcción del edificio mismo y la disposición del sitio son incluídas, así como también las precauciones tomadas desde el punto de vista de la seguridad, del purgado de agujeros experimentales por dióxido carbónico hasta los arreglos para evacuación, recirculación de aire y refriega, y lavado de las paredes en el caso poco probable de una excursión de reactor.



View of the aluminium tank during construction.

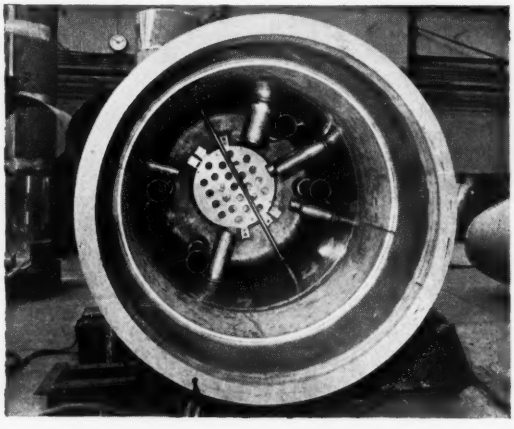
Aluminium Tank

Inside the graphite is the aluminium tank containing the heavy-water reflector and the reactor core. This tank, manufactured by the A.P.V. Co. Ltd., is of 99.8% pure aluminium and has a number of nozzles for coolant inlets and outlets, as well as thimbles for experimental holes and the "false-bottom" plenum chamber, and represents quite a complicated piece of welding to unusually exacting standards, one of which was the necessity of identical analysis of the weld metal and parent metal. As shown during manufacture, the vessel is fitted with four legs. These serve to support the vessel during the welding of the coolant pipes, but are afterwards removed, the vessel being supported by its top flange.

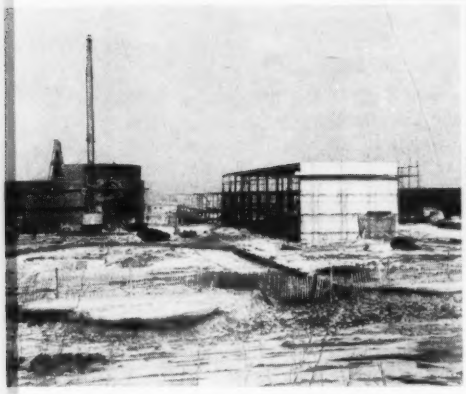
Top Shielding

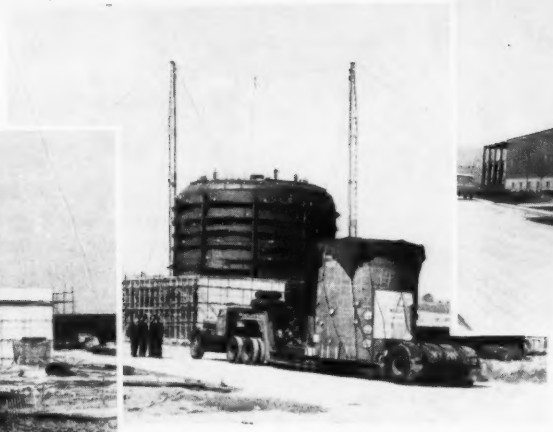
The construction of the reactor top is rather complicated and not easy to follow from the drawings. Resting on a flange on the steel tank is an annular box 10 ft. 7½ in. o.d. made of steel and lined with 2 mm of cadmium; 4 in. of lead with cast-in cooling pipes; the remainder being filled with concrete. Above this is a second annular box, containing concrete only. On top of this is a steel ring which provides a rebate for supporting the flange of the aluminium tank. Above this again, resting on stools on the framework is a 10-in.-thick segmental cast-iron ring which supports the main top plate and provides a void or gap to accommodate pipes and cables, etc.

View inside the aluminium tank during construction.



Above: DIDO complete.





Stages in construction: Above, the steel tank arrives.

In the centre of the annular concrete boxes is a cylindrical box which shields the aluminium tank. Constructed of stainless steel, this circular box contains 2 mm of cadmium, 4 in. of water-cooled lead and 3 ft. 3 in. of iron-shot concrete of density 5.6, with a 2-in.-thick stainless-steel master plate on top. Both the cylindrical box and the two annuli are suitably stepped in diameter to prevent direct radiation.

On the very top, resting on the cast-iron ring, is the reactor top plate, made of steel 10 in. thick in two concentric pieces. The top surface of this plate, which was manufactured by Thos. Firth and John Brown Ltd., is level with the chequer-plating of the working floor.

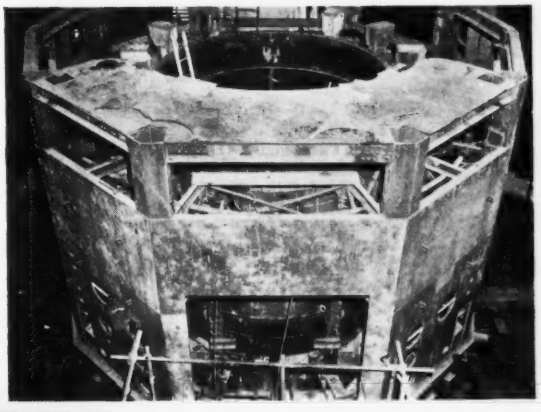
Horizontal Shielding

As already noted, the main steel tank provides boral and water-cooled lead shielding as well as two layers of steel. The remainder is provided by barytes concrete, approximately 5 ft. thick, cast between the steel tank and the outer steel plating of the bandstand-like structure. This concrete, incidentally, is not designed to support the weight, which is all carried by the steel framework.

On the lower floor, the space between the four vertical columns is utilized as an auxiliary plant room for the heavy-water plant. Heavy sliding doors for shielding purposes were manufactured by the Motherwell Foundry Ltd.

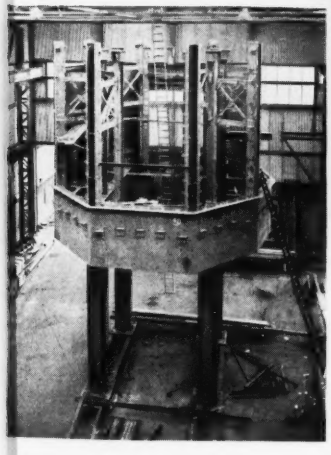
D_2O Circuits

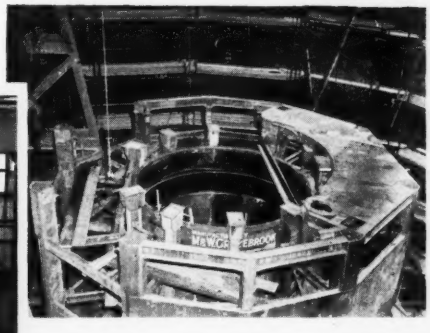
As can be seen from the illustration of the aluminium tank, there are three inlets for the heavy water leading to the manifold or plenum chamber into which the fuel elements are fitted. There are also four outlets which take the form of bell-mouthed weir pipes at about the level of the outlet ports from the fuel elements, i.e., approximately 30 in. below the normal level of the heavy water, this upper layer acting as a reflector and having a very considerable effect on the reactivity. There is also an overflow pipe at the upper level. There is, in addition, a drain pipe which is normally never used and which is fitted with a locked valve. The flow of heavy water entering the chamber at the bottom of the aluminium tank is through the spaces between the fuel-element plates (the velocity has been given as between 11 and 12 f.p.s.), out of the fuel-element ports and through the 7-in. weir pipes and to a common header, feeding the pumps through Saunders valves.



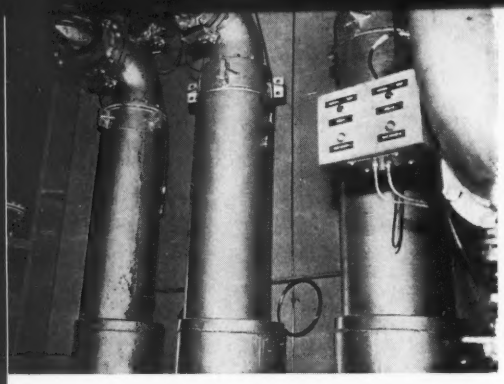
The three main pumps are of the glandless type, designed and manufactured by Hayward Tyler Ltd. generally on the lines shown in the diagram. Both the pump and motor are enclosed in a stainless-steel shell, flanged at each end to form the inlet and outlet for the suction and discharge. This construction completely eliminates leakage, since the only opening in the casing is a small cable gland. Stainless steel and aluminium are used throughout. Both thrust and

Below: Trial erection of the steelwork at Wright Anderson's works.





Above, and on right: Two views of the steelwork during construction with the steel tank in position.



The main heavy-water pumps (sectional drawings are shown on the pull-out facing p. 15).

journal bearings are of the tilting pad type, employing stainless-steel pads with thrust disc and journal sleeves of plastics. These motors, incidentally, were assembled under conditions of surgical cleanliness to exclude any possibility of contamination.

Two stand-by pumps are provided for emergency conditions, these being manufactured by Hydraulic and Mechanical Developments Ltd. The HMD pump eliminates leakage by the use of a magnetic coupling operating through a stainless-steel shroud.

The main heavy-water coolers are of the shell and tube type, manufactured by Head Wrightson Processes Ltd. They are of stainless steel, the heavy water being confined to the tube section. From the coolers, the heavy water passes to the tank inlets. All pipes, valves and manifolds are of stainless steel.

The main heavy-water storage tank is of stainless steel. Fabricated by Robert Jenkins Ltd., it has a capacity of approximately 9¼ tons of heavy water.

To reduce the reactivity, either in emergency or for a long shut-down, it is possible to remove the upper reflecting layer of heavy water by a "partial dump" system. A dump valve (actually a modified Fisher governor valve), push-button operated from the control panel, allows the heavy water to flow into the partial dump tank. This, manufactured by Metal Propellers Ltd. in stainless steel, is of exactly the right capacity to accept the required amount and no more, so that the level in the reactor cannot fall below the tops of the fuel elements.

After a partial dump, the heavy water is returned to the reactor by a transfer pump. This is of the HMD magnetic-coupled type and has a capacity of some 30 gal./min. It operates automatically in the event of any leakage in the partial dump valve and its main function is to keep the partial dump tank empty, starting automatically when a predetermined quantity of heavy water has leaked past the dump valve, and stopping before the dump tank is completely empty, so leaving the pump primed and preventing possible damage to the bearings. It is interlocked so that it will not run when the partial dump valve has been opened and so that it cannot be manually started when the partial dump tank is empty. On initial filling of the reactor, from the main heavy-water storage vessel, the pump is arranged to cut out by a Foxboro-Yoxall level controller when the level in the reactor is within ½ in. of the overflow pipe, the remaining increase in level being carried out by the liquid-level pump. This (or rather these, since there is a main and a stand-by unit, both of the HMD magnetic-coupled type) is of considerably smaller capacity (5 gal./min.). The function of the liquid-level pump is to maintain the level in the reactor absolutely constant by supplying a small constant flow of heavy water to the tank, the surplus running down the overflow pipe back to the main storage vessel. Should this flow cease, the reactor automatically shuts itself down.

Guaranteed electrical supplies are available for all pumps required when the reactor is shut-down, i.e., shut-down heavy-water circulators, liquid level pumps and the emergency light-water-cooling pumps.

Purification of the heavy water is carried out by an ion exchanger designed by A.E.R.E. using Permutit resins. The unit can be by-passed if required.

H_2O Circuits

The heavy-water coolers are fed on the secondary side with light water circulated through cooling towers. The cooling pipes, 10 in. in diameter, have extra shielding in the form of lead muffs where they emerge from the heavy-water plant room, and are connected through valves to manifolds which are fitted with scintillation counters. The pressures in the heavy-water coolers are intentionally kept higher on the D_2O side, so that any leakage that could occur would be outwards, and cooling water could not contaminate the reactor. The scintillation counters would therefore give warning of any leakage and the consequent release of small amounts of radioactivity into the cooling water.

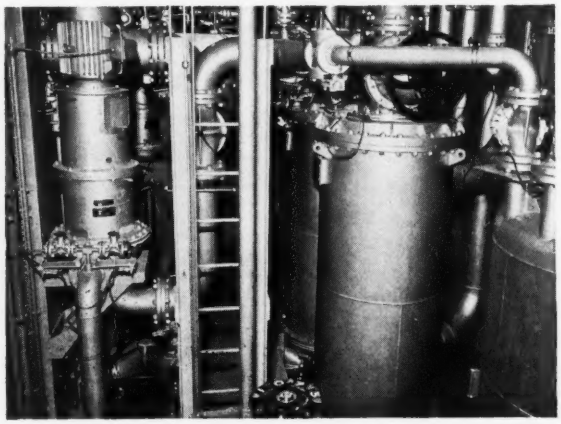
Circulation of the main cooling water is by means of horizontal centrifugal pumps manufactured by Gwynne's Pumps Ltd., located in a separate pump-house between the reactor building and the cooling towers. There are six pumps in all, four main and two emergency. Three main pumps are required for full power operation, leaving one as a stand-by unit. Of the two emergency pumps, one runs during shut-downs and the other is a stand-by, starting automatically if the running pump fails.

There are, in addition, a number of auxiliary cooling circuits. For the shield cooling, demineralized water is circulated through a closed circuit from a header tank via two Worthington-Simpson pumps (one stand-by) and a heat exchanger cooled from a tapping off the main cooling-water supply. The cooling system for the fine control rod utilizes demineralized water on both sides of the heat exchanger (made by Marston Excelsior Ltd.) and a separate header tank. Circulation is by means of two Mono pumps (one stand-by) driven by ¼-h.p. Brook motors. The heat-exchanger cooling water, i.e., the secondary side, is in this case cooled by the actual cooling water used for the shield circuit.

Cooling circuits are also available for experiments in progress in the reactor holes, the experimental circuits utilizing two Mopumps (Rhodes, Brydon and Youatt Ltd.) driven by 11-h.p. motors.

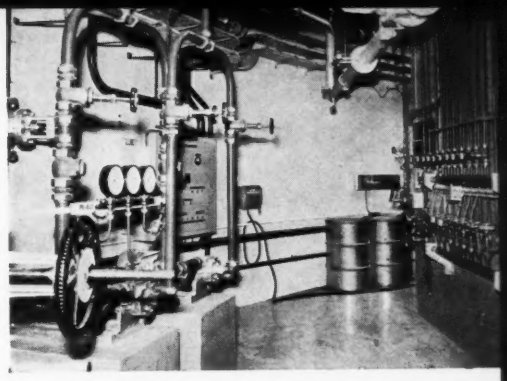
Demineralized water is used in this circuit, purification being carried out in a 5 to 15-gal./hr. ion-exchange unit, using Permutit resins. For the make-up water to the main

The stand-by heavy-water pumps (section on pull-out) and the main heavy-water coolers. On the right can be seen part of the partial dump tank.



cooling circuit there is a Permutit Ltd. treatment plant with a capacity of 5,000 gal./hr.

The cooling towers themselves are of the mechanical-draught type, built by Head Wrightson Ltd. This type of tower was described in *Nuclear Engineering* for November, 1956.

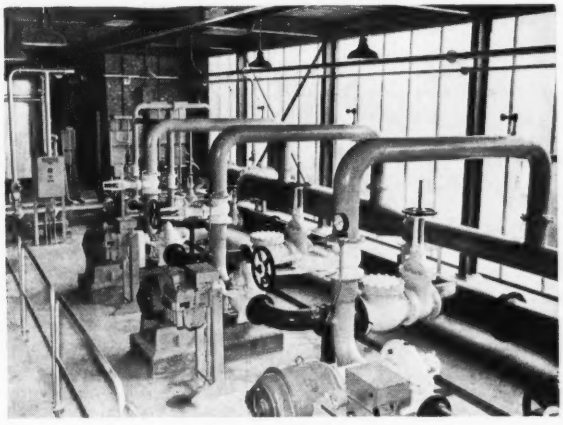


The shield cooling pumps and piping.

Helium Circuits

An inert atmosphere of helium is used throughout the reactor and heavy-water system to exclude air and to act as a balance when heavy water is moved from one part of the system to another. It has, too, another important function, in that it acts as a vehicle for the removal of gas formed by irradiation.

There are two gasholders, built by Ashmore, Benson Pease and Co., both being of the diaphragm-sealed floating-piston type, maintaining a constant pressure in the system. One, for the heavy-water system, is 10 ft. in diameter and 9 ft. high. The other, for the graphite space, is somewhat smaller, being 6 ft. in diameter and 6 ft. high. There is also an expansion vessel, of 1,000 cu. ft. capacity, made from stainless-clad mild steel by W. J. Fraser and Co. Ltd. connected to the reactor through an 8-in. balance line, which allows for any pressure rise in the reactor due to power excursion. Should such a pressure rise occur,



Circulating pumps in the external pump-house.

the gasholder is protected by two quick-closing valves arranged in series.

The helium circuits are, in fact, quite complicated, on account of the operational flexibility provided. It is possible, for example, to remove helium from any part of the circuit and return it to the same point after passing it either through a drier and absorber unit or through a catalytic recombination unit. The first is used for removing air or other gases from the circuit (some air must inevitably enter the system when changing fuel elements) and was manufactured by the British Oxygen Engineering Co. Ltd., who were responsible for the engineering of much of the helium circuitry. Liquid nitrogen is used in this unit for cooling purposes.

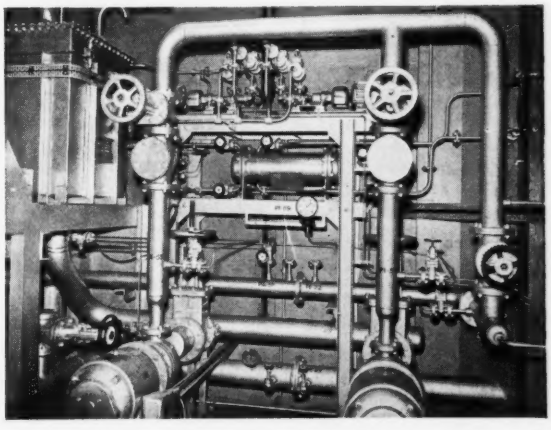
The recombination unit was manufactured by Baker Platinum Ltd. and its function is to recombine deuterium and oxygen resulting from dissociation of the heavy water.

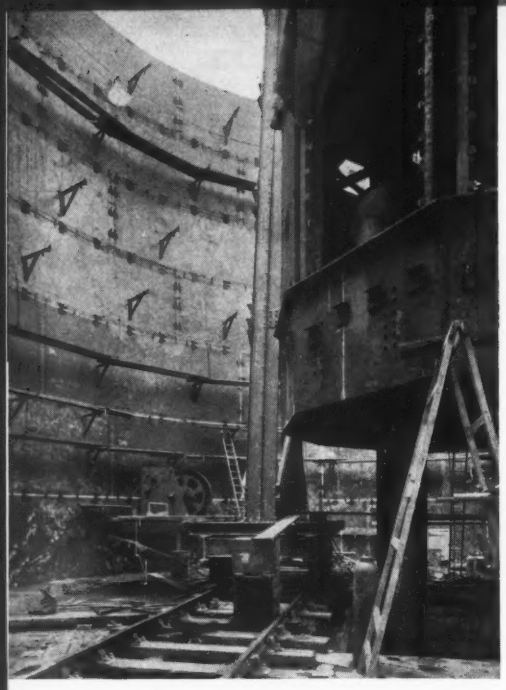
Circulation of the helium is carried out by what are commonly referred to as "blowers", but are, in actual fact, slow-speed diaphragm pumps driven through double-reduction gearing by Brook motors. The pump units were manufactured by E.C.D. Ltd., of Tonbridge, and there are five blowers in all, one being a single unit, associated with the platinum catalyst circuit, the capacity being given as 180 cu. ft./hr. The other four are actually two twin units, each with two blowers in parallel, driven by a single motor. These units can either be used as main and stand-by or, when required, can be used together.

Fuel Changing

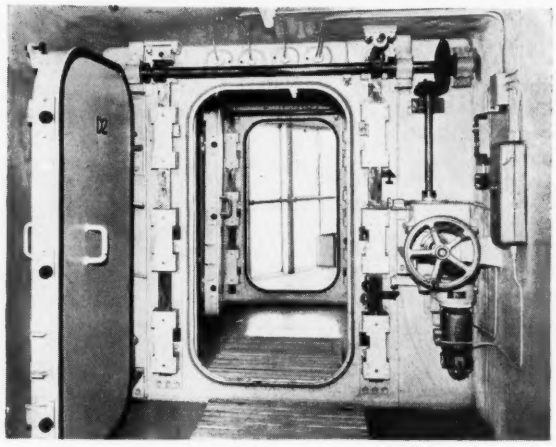
With a highly-enriched fuel and an output of such magnitude, the fuel elements (which are changed about every two weeks after a 12-hour shut-down) are in a very "hot" condition in both radioactive and thermal senses. The radiation from fission-product activity is, in fact, of the order of megacuries and it has been stated that, unshielded, the radiation from a removed element would give something like 10^6 times the normal tolerance level at a distance of 10 ft. Furthermore, the heating would be such as to produce melting in a matter of minutes, once cooling ceases. The design of fuel-changing mechanism therefore presented quite formidable problems, and the flask or coffin, designed by Head Wrightson Processes Ltd. and manufactured by Robert Jenkins Ltd., is of necessity an ingenious piece of equipment. It consists, in effect, of a stainless-steel tube some 12 in. in diameter by 15 ft. long surrounded by a 12-in. thickness of lead shielding. A sliding lead-shielded circular door covers the lower end of the flask, which contains a revolving magazine with two compartments, and the necessary winch gear and grab mechanism. In operation, a plug is first withdrawn from the reactor top plate and an adaptor, rather like a very large version of a bush for a drilling jig, is placed in position to bridge the void between the reactor top plate and the master plate, to avoid the entire helium content of the reactor being replaced by air. The flask is then lowered

Pumps and heat exchangers for the experimental circuits (foreground). At the rear are the heat exchanger and pumps for the fine control rod cooling circuit.





Left: During construction, showing the pressure shell and the reactor steel-work.

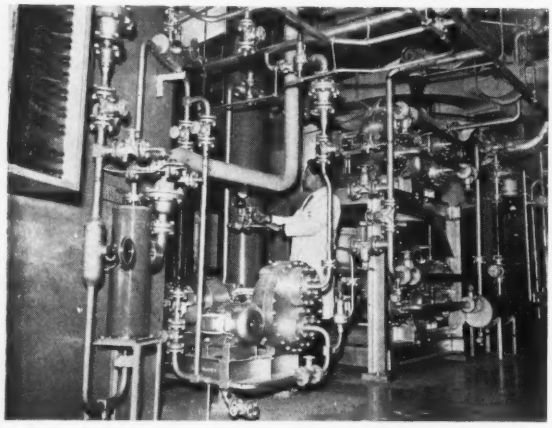


Right: The personnel air lock, with both doors open before operation began.

by crane into a locating rebate in this bush, and the grab lowered to remove the element from the reactor.

The grab is of the gravity-operated type, to avoid any possibility of the element being dropped in the case of a power failure during hoisting. The element is hoisted into the flask, the magazine revolved and a fresh fuel element lowered into position. The door is then closed and the flask is removed to dump the old element.

It has already been pointed out that the irradiated element cannot last for more than a few minutes uncooled. As the element is withdrawn, the air contained in the flask



Above: Helium blower plant. At the extreme left can be seen the terminal board for the fuel-storage block thermocouples. On right: DIDO in a completed state.

will drop into the reactor, displacing some of the helium into the flask. (The method of dealing with the air in the reactor has already been explained.) The atmosphere in the flask, which may be helium or a mixture of air and helium, is rapidly circulated by a blower system built into the flask, being cooled by means of an air-cooled heat exchanged. An additional refinement is the provision of a cold trap for recovering heavy water dragged out with the fuel element and vaporized by the fission-product heat.

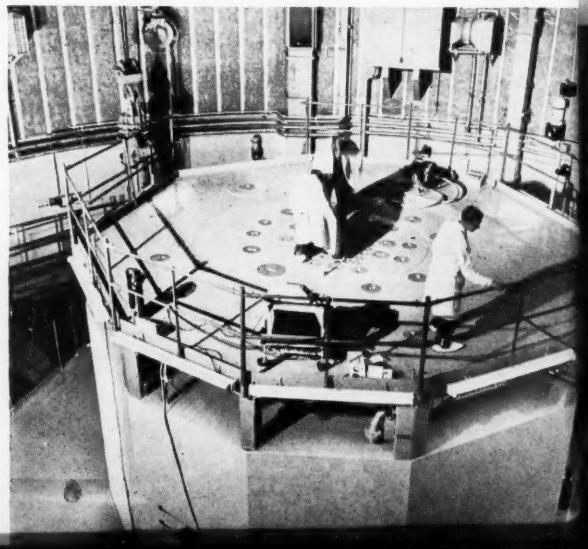
The irradiated element is dumped into one of the holes in a heavy concrete fuel-storage block beneath operating-floor level, where it is allowed to cool for the appropriate period, the block being air-cooled by means of the main ventilating system. Thermocouples are provided in each element-storage hole, a temperature recorder being connected to any one as required.

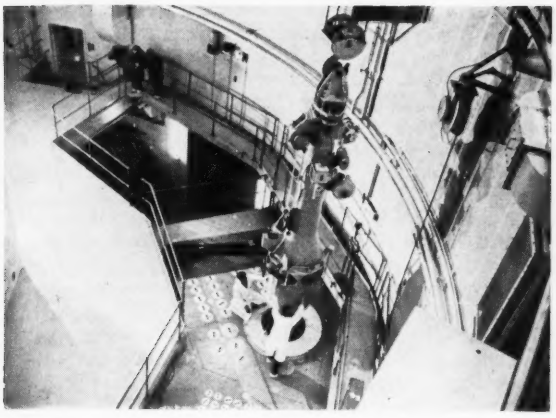
Buildings

DIDO consists of a number of buildings, as can be seen by the illustration of the site model but the most interesting is the reactor house itself. Should a power excursion occur of such magnitude as to boil off the heavy water in the reactor, it would cause a highly active atmosphere at a pressure above the outside air and, to contain this, the building has been designed as a pressure vessel. During normal operation, the pressure within the building is kept at about $\frac{1}{8}$ in. w.g. below atmospheric; this ensures that any leakage is into, not out of, the building so tending to confine any airborne activity, rather than releasing it to the atmosphere.

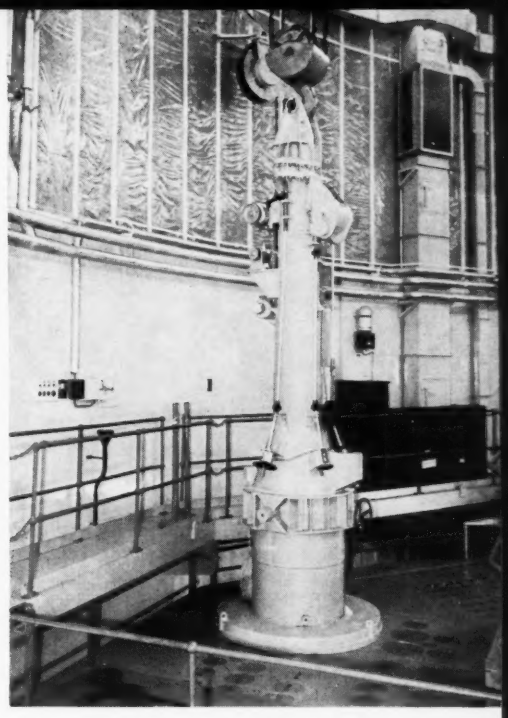
The civil engineering work on the site was carried out by W. E. Chivers Ltd. and the foundation is a solid concrete raft.

The building, by Whessoe Ltd., is built as a pressure vessel to Lloyd's Class A regulations. The plate used for the shell is graded from $\frac{15}{16}$ in. at the ground level to $\frac{1}{2}$ in. at the top of the dome, the majority of the wall up to the bend being $\frac{13}{16}$ in. Welded throughout and all welds X-rayed, the building is a cylindrical, flat-domed structure some 70 ft. in diameter and 70 ft. high. Plates were bent before being sent to the site, and it it has been stated that the shell is of adequate strength without the channel reinforcement. There is a steel diaphragm acting as the floor of the building, this having a sunken portion in the centre to form the sump of the heavy-water plant room.





Left: The element flask or coffin being lowered.



Right: Another view of the fuel-element flask.

The walls are lined inside with 2-in. Fibreglass and covered with a "wallpaper" of polythene sheeting. Differential air pressures inside and outside the shell are maintained by means of an air-lock system. There are three air locks in all: one normally used for foot passengers; one for vehicles, between the reactor hall and the active handling bay; and one an exit for personnel in case of emergency direct to the outer air. Doors for air locks were provided by J. Stone Ltd.

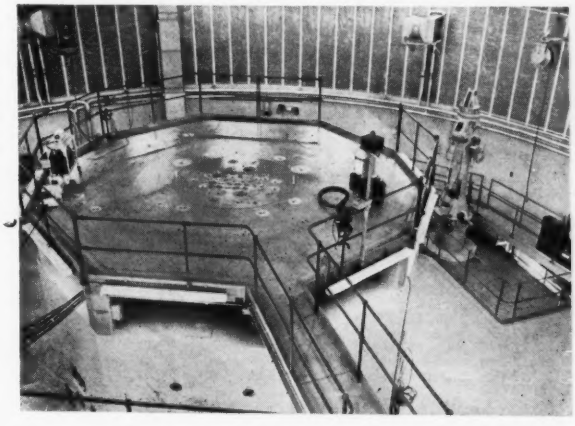
Ventilation

Since the shell is sealed, the problem of ventilation is one of considerable importance. Ventilation plant was provided by the Andrew Machine Co. Ltd. and the capacity of both inlet and outlet fans is some 4,500 cu. ft./min. Arrangements are made for incoming air to be either dried or humidified, heated or cooled, to permit the most desirable working temperature and humidity to be maintained. The refrigeration plant was provided by the Lightfoot Engineering Co. Ltd. The inlet air is blown in through the louvres high up in one wall, but the extract air, to avoid "pocketing", is taken from several locations with particular attention to portions of the buildings which would normally tend to form pockets of dead air. Inlet air is washed and outlet air is filtered.

Additional ventilation is provided for the control room, which is semi-enclosed and is, in any case, naturally a hot spot on account of the number of instruments located there. The additional ventilation merely consists in providing extra flow of the main ventilating air through this particular portion. This is ensured by a large-diameter trunking. The fan used is an axial-flow unit by Woods of Colchester.

Safety

Unlikely as an excursion of any magnitude may be, the prospect is one that has to be contemplated, and the necessary steps taken to avoid the spreading of contamination. The pressing of the scram shut-down button on the control panel automatically shuts off the ventilation inlets and outlets, leaving the building sealed. If necessary, the building would be evacuated by the emergency air lock and the



Above: A general view of the reactor top plate. Left: Placing the graphite during construction.

emergency control room (located outside the building) would be manned.

To remove airborne particles carrying radiation, the entire air content of the building can be recirculated and washed in a Peabody gas scrubber, this plant being located outside the building (see the view of the site model). At the same time, the entire inner wall of the building could be washed down by a sprinkler system, the water draining into the sump from which it could later be pumped to the effluent system.

Instrumentation

The complete instrumentation of DIDO may probably form the subject of a subsequent article and space only permits a very brief summary. The instrument panels and the installation were carried out by Hutcheon, Duthie and Son Ltd. Not all the instruments, of course, are located

A view of the main control panel.

in the control room. The instrumentation of a project of this nature falls into several different categories, such as pressure and temperature indication and control, flow indication, liquid-level indication and special items such as health monitoring. This last item, incidentally, is covered very thoroughly. Dispersed in various locations around the building are no fewer than 16 γ monitors (Isotope Developments Ltd.) and six fast neutron monitors. In addition, the outlet filters are monitored for γ-emitting dust particles.

Crane

An interesting piece of non-nuclear equipment was the crane, which is said to be the first example in this country of a gantry crane running on a circular track. Rated at 20 tons, it has a hoisting speed of 20 ft./min. and a cross-traverse speed of 60 ft./min. What on a normal straight track would be called the long travel motion, has a speed of 125 ft./min. at the track so that, the track being 66 ft. 6 in. in diameter, a complete revolution would take about 1½ min. The crane was built by the Wharton Crane and Hoist Co. Ltd., and is d.c.-operated from a mercury arc rectifier. Creeping speeds are provided on all motions.

Experimental Facilities

DIDO contains a total of 28 vertical and 11 horizontal holes, in addition to a thermal column 5 ft. square, the door of which is composed of steel and Jabroc (compressed laminated wood). The graphite blocks can be removed in sections to give additional flexibility. The actual facilities available are shown facing p. 15.

In order to avoid the risk of active argon being released from the experimental holes, facilities are available for purging any hole with CO_2 before opening up. CO_2 is available at various points around the reactor face, and exhaust ring mains are provided for both horizontal and vertical facilities.

In order to facilitate the handling of experimental work, a considerable amount of work can be done in the active handling bay, the building next to the reactor shell. Here a space 106 ft. long by 33 ft. wide is available together with remote-handling apparatus, cooling pond, 20-ton crane and changing-room facilities.

We should like to acknowledge the facilities afforded by A.E.R.E., Harwell, for studying this reactor and obtaining information at first hand.

The general design of the reactor and its associated plant and buildings was carried out by an A.E.R.E. team in conjunction with the Ministry of Works and Head Wrightson Processes Ltd., who were responsible for the detailed design of the reactor.

CONTRACTORS

(Many of these were sub-contractors to Head Wrightson Processes Ltd.)

ALUMINIUM PLANT AND VESSEL CO. LTD., Manor Royal, Crawley, Sussex
Reactor vessel; stainless steel; heads for fuel element and experimental facilities.

ANDREW MACHINE CO. LTD., 52 Grosvenor Gardens, London, S.W.1
Ventilation equipment.

ASHMORE, BENSON, PEASE AND CO., Parkfield Works, Stockton-on-Tees
Gasholders.

B.K.L. ALLOYS LTD., Birmingham Factory Centre, King's Norton, Birmingham
Fabrication of stainless-steel piping and fittings.

BAKER PLATINUM LTD., 52 High Holborn, London, W.C.1
Helium recombination unit.

BRITISH OXYGEN ENGINEERING LTD., Angel Road, Upper Edmonton, London, N.18
Helium drier and absorber.

BROOK MOTORS LTD., Empress Works, Huddersfield
Electric motors.

BRUSH ELECTRICAL ENGINEERING CO. LTD., Loughborough, Leics.
Electrical continuity sets.

W. E. CHIVERS AND SONS LTD., Devizes, Wilts.
Civil works.

E.C.D. LTD., Priory Works, Tonbridge, Kent
Helium blowers.

EVERSHED AND VIGNOLES LTD., Acton Lane Works, Chiswick, London, W.4
Instruments.

THOMAS FIRTH AND JOHN BROWN LTD., Atlas Works, Sheffield, 4
Reactor top plate.

FOXBORO-YOXALL LTD., Lombard Road, Merton, London, S.W.19
Instruments.

W. J. FRASER AND CO. LTD., Harold Hill, Romford, Essex
Stainless-clad mild-steel expansion vessel.

M. AND W. GRAZEBROOK LTD., Netherton Iron Works, Dudley
Thermal column frame and door; reactor stool; reactor steel tank.

GWYNNES PUMPS LTD., 62/64 Chancellor's Road, London, W.6
Main C.W. pumps.

MATTHEW HALL AND CO. LTD., 26 Dorset Square, London, N.W.1
Mechanical plant.

HAWKER SIDDELEY NUCLEAR POWER LTD., 18 St. James' Square, London, S.W.1
Boral shielding.

HAYWARD TYLER AND CO. LTD., Crawley Green Road, Luton, Beds.
Main heavy-water circulating pumps.

HEAD WRIGHTSON PROCESSES LTD., 24 Baltic Street, London, E.C.1
Cooling towers.

HEAD WRIGHTSON AND CO. LTD., Teesdale Ironworks, Thornaby-on-Tees
Erection; cooling plant; shields.

H. M. HOBSON LTD., Fordhouses, Wolverhampton
Control mechanism.

HONEYWELL-BROWN LTD., Wadsworth Road, Perivale, Middx.
Instruments.

R. HUTCHEON, DUTHIE AND SON LTD., 18 David Road, Poyle Trading Estate, Colnbrook, Bucks.
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HYDRAULIC AND MECHANICAL DEVELOPMENTS LTD., 116 Victoria Street, London, S.W.1
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ISOTOPE DEVELOPMENTS LTD., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks
Instruments.

ROBERT JENKINS AND CO. LTD., Ivanhoe Works, Rotherham, Yorks.
Heavy-water vessels; shielded handling flasks for active equipment.

GEORGE KENT LTD., Luton, Beds.
Instruments.

LANG BRIDGE LTD., Spring Hill Works, Accrington, Lancs.
Shield plugs and heads for experimental facilities.

LIGHTFOOT REFRIGERATION CO. LTD., Abbeydale Road, Wembley, Middlesex
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LONDON ALUMINIUM CO. LTD., Westwood Road, Witton, Birmingham, 6
Aluminium experimental facility thimbles.

MARSTON EXCELSIOR LTD., Fordhouses, Wolverhampton
Fuel element fabrication.

METAL PROPELLERS LTD., 74 Purley Way, Croydon, Surrey
Heavy-water vessels.

MONO PUMPS LTD., Mono House, 1 Sekforde Street, London, E.C.1
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SAMUEL OSBORN AND CO. LTD., Clyde Steel Works, Sheffield
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HENRY W. PEABODY (INDUSTRIAL) LTD., 17 Gt. Suffolk Street, London, S.E.1
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READ AND PARTNERS LTD., 28-32 Hatfields, Stamford Street, London, S.E.1
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RHODES, BRYDON AND YOUATT LTD., Waterloo Engineering Works, Gorsey Mount Street, Stockport
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WHESSOE LTD., 25 Victoria Street, London, S.W.1
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WORTHINGTON-SIMPSON LTD., Lowfield Works, Newark
Shield cooling pump.

DIDO Control System

by

L. W. J. NEWMAN, B.Sc., A.R.C.S., D.I.C., Ph.D., A.F.R.Ae.S.

Head of Nuclear Engineering Department, H. M. Hobson Ltd.

Using cadmium neutron absorber, the system comprises six coarse control shut-off units of the signal-arm type, a single fine control rod, and two safety rods. The control arms are driven through slave gearboxes ganged electrically to a master gearbox, whilst the fine control is operated from a gearbox controlled by a closed-loop servo system.

THE control system is an important feature of the design of any reactor. It must embody features which permit the power level to be set and maintained at a required value, must compensate for variations in that level due to burn-up of the fuel and production of fission product poison, must ensure the safe operation of the reactor at all times and provide the means of shutting-down in the event of any form of failure which might give rise to a power excursion. For DIDO, the design of the control system, which was further conditioned by space limitations, was undertaken in collaboration with the Reactor Division at Harwell by H. M. Hobson Ltd. of Wolverhampton.

The specification called for the control system to be divided into three main groups. The coarse control/shut-off group is required to arrange that the power level may be set at the desired figure and to contain sufficient neutron-absorbing material (cadmium sheet) to remove excess reactivity in the reactor and shut the reactor down

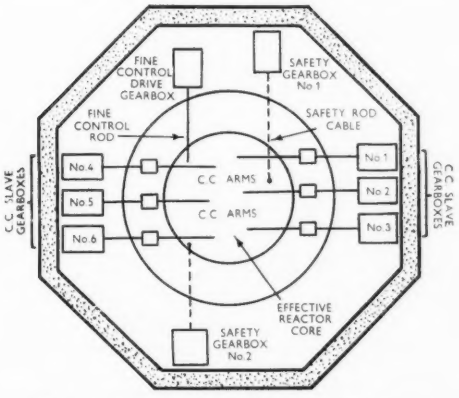


Fig. 1. Arrangement of DIDO control system.

when necessary or when a fault occurs to cause automatic shut-down. The fine control or regulating group is required to provide rapid compensation for the comparatively small deviations from the set power level due to burn-up, etc., and is designed for push-button or automatic operation. Finally, the safety rods, which provide additional absorber and which can be released by gravity, fall into the reactor to remove any excess reactivity which may arise in the shut-down condition or during loading or the change of experimental set-ups.

Coarse Control Shut-off Group

There are six identical coarse control/shut-off units which take the form of cylindrical controllers containing the operating mechanism terminating in blades of the signal-arm type. Each control arm is driven through a slave gearbox, these being ganged electrically to a master gearbox situated in the reactor control room.

Coarse Control Arm. The cadmium absorber, in the form of sheet 0.080 in. thick, is sealed by argon-arc welding between 20 S.W.G. stainless-steel sheets to protect it from the action of the heavy water. The steel sheath is welded to a stainless-steel (18/8/1) cast pivot to form the signal arm 4 ft. 10 in. in length which is pivoted 3 in. above the maximum heavy-water level. Stainless-steel roller bearings are provided which have to operate without the usual lubricants, using only water. The arm is horizontal in the "out" position and moves downward into the core. The geometry of the system dictates that the maximum absorber area, some 12,000 cm^2 of cadmium, is in the core when the arm has described an arc of 56°.

The arms operate in the spaces between the fuel elements and are arranged three on each side of the

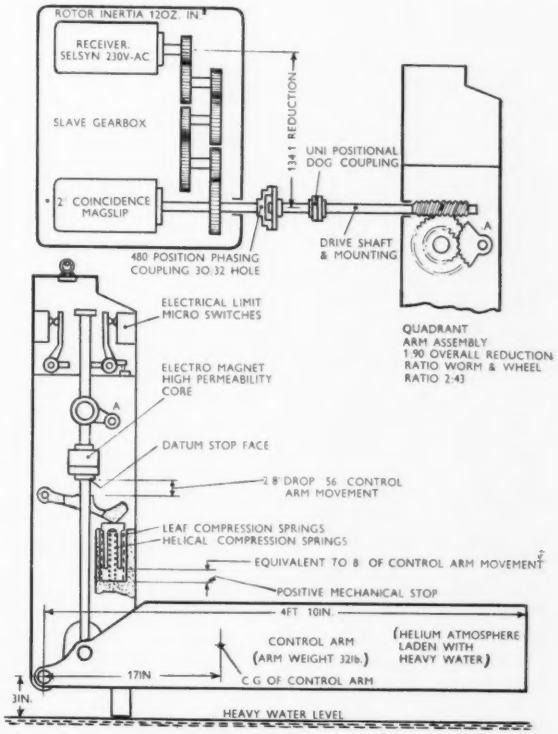


Fig. 2. Basic coarse control system slave gearbox and control arm.

reactor. A complete coarse controller is inserted through the reactor top plate and biological shield and is housed in a stainless-steel static sleeve. The control arm is designed so that it can be rotated through 90° from the horizontal to permit entry and withdrawal of the assembly through this sleeve.

The specification called for the normal speed "in" and "out" of the control arm of 0-56° in 25 minutes and an additional "fast in" speed of 5 minutes. These speeds are achieved by suitable reduction gearing from the motors driving the master selsyn in the master gearbox itself, in the slave gearbox and in the coarse control arm mechanism. A block schematic diagram of the system is shown in Fig. 2, from which it will be seen that a reduction of 90:1 is provided in the coarse controller itself. This is achieved by a worm/worm-wheel drive and spur gearing situated in the head unit, which also contains an electro-magnetic clutch and the limit switches which provide warning light indicators on the control desk at the extremes of control arm movement.

Fig. 3 shows a sectional view of a complete coarse control unit. It is closed at the top end with a locked cover which can only be unlocked with the key which is normally housed in a master switch located in the control room. Removal of this key from the master switch causes the rods to fall to the fully "in" position, so that access to the coarse controller mechanism cannot be obtained unless the reactor is shut-down. The electro-magnetic clutch is housed below the reduction gears, and when de-energized the arm will fall freely under gravity to the 56° position in less than one second. The energy of the falling control arm is absorbed in a system of ring springs. The connecting rod which operates the control arm passes through a shielded plug portion made of stainless steel, the spaces in which are filled with heavy concrete made from Portland cement and iron shot. Additional neutron shielding during the sideways motion of the connecting rod is provided by a stainless-steel shutter at the bottom end. The parts of the controller which are near to the reactor core are all made from stainless-steel castings, forgings and tubes which are welded into assemblies by the argon-arc process.

Helium from the blanket covering the surface of the heavy water is prevented from escaping past the moving parts by means of a long, double stainless-steel bellows assembly. Neoprene ring seals prevent helium loss between the controller and the outer sleeve in which it is located in the biological shield. Test points connected by pipes between the seals and between the inner and outer bellows provide means of testing that active helium is not escaping.

When it is desired to change a coarse control arm, the arm can be positioned vertically by unlocking the stop mechanism. The reactor must be shut-down, which is ensured by the locking arrangements on the control arm cover previously described; the drive shaft coupling and electrical leads are disconnected. The cover is removed, lifting eyes are screwed into the tapped holes provided in the top of the unit, the locking ring removed and an extension tube is placed down through the top plate to locate in the breech tube. A specially designed shielded flask is then used to withdraw the control arm, the extension tube forming a seal to prevent loss of helium from the reactor. A replacement coarse control arm can be installed by reversing the process, for which purpose, a less heavily shielded flask can be used.

Servicing of the complete unit is normally impossible, except for the greasing of the reduction gear which can be performed through the access hole provided in the top plate. The unit has therefore been designed to require the minimum of maintenance, and two spare controllers are provided in sealed containers to prevent contamination.

Slave Gearbox. The six coarse controllers are driven by six slave gearboxes each containing a slave selsyn fed from one channel of the master selsyn, which is situated in the master gearbox. The output shaft is geared down 134 to 1 from the slave selsyn by a train of spur gears, and is coupled to the appropriate coarse controller by a tubular drive shaft. At the gearbox end there is a vernier phasing coupling (480 positions) and at the controller end a dog coupling.

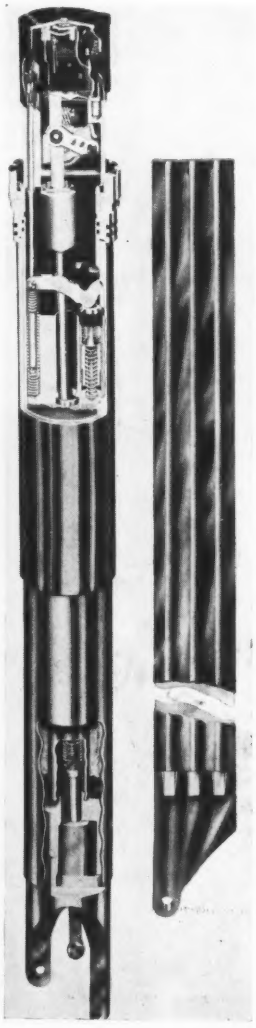
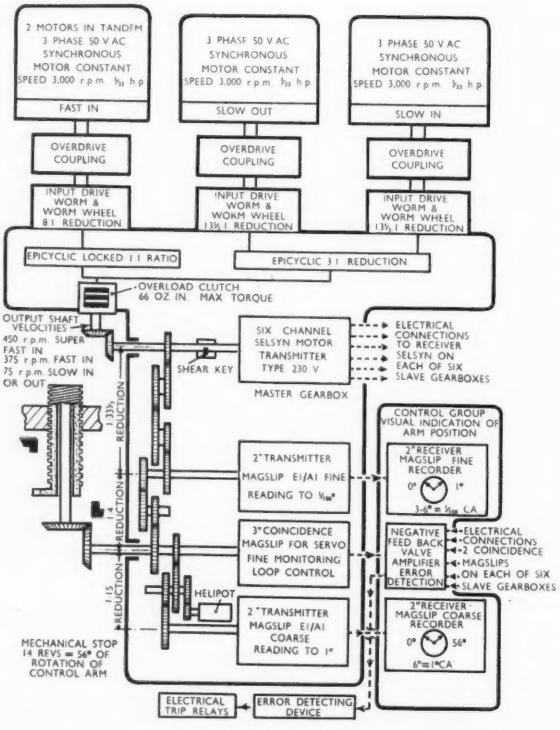


Fig. 3 (left). Section of coarse control unit.

Fig. 4 (below). Basic coarse control master gearbox and transmitting system.


2 MOTORS IN TANDEM 3 PHASE 50 V AC SYNCHRONOUS MOTOR CONSTANT SPEED 3,000 r.p.m. 1/33 h.p.
FAST IN
3 PHASE 50 V AC SYNCHRONOUS MOTOR CONSTANT SPEED 3,000 r.p.m. 1/33 h.p.
SLOW OUT
3 PHASE 50 V AC SYNCHRONOUS MOTOR CONSTANT SPEED 3,000 r.p.m. 1/33 h.p.
SLOW IN
OVERDRIVE COUPLING
OVERDRIVE COUPLING
OVERDRIVE COUPLING
INPUT DRIVE WORM & WORM WHEEL 81 REDUCTION
INPUT DRIVE WORM & WORM WHEEL 133 1/3 REDUCTION
INPUT DRIVE WORM & WORM WHEEL 133 1/3 REDUCTION
EPICYCLIC LOCKED 1:1 RATIO
EPICYCLIC 3:1 REDUCTION
OVERLOAD CLUTCH 66 OZ. IN. MAX TORQUE
OUTPUT SHAFT VELOCITIES 450 r.p.m. SUPER FAST IN 375 r.p.m. FAST IN 75 r.p.m. SLOW IN OR OUT
SHEAR KEY
SIX CHANNEL SELSYN MOTOR TRANSMITTER TYPE 230 V
MASTER GEARBOX
ELECTRICAL CONNECTIONS TO RECEIVER SELSYN ON EACH OF SIX SLAVE GEARBOXES
CONTROL GROUP VISUAL INDICATION OF ARM POSITION
2" RECEIVER MAGSLIP FINE RECORDER
2" TRANSMITTER MAGSLIP E1/A1 FINE READING TO 1/100°
3" COINCIDENCE MAGSLIP FOR SERVO FINE MONITORING LOOP CONTROL
NEGATIVE FEED BACK VALVE AMPLIFIER ERROR DETECTION
ELECTRICAL CONNECTIONS 2 COINCIDENCE MAGSLIPS ON EACH OF SIX SLAVE GEARBOXES
HELIPOT
2" TRANSMITTER MAGSLIP E1/A1 COARSE READING TO 1°
2" RECEIVER MAGSLIP COARSE RECORDER
MECHANICAL STOP 14 REVS = 56° OF ROTATION OF CONTROL ARM
ELECTRICAL TRIP RELAYS
ERROR DETECTING DEVICE

The working parts of the gearbox are housed in a cast aluminium alloy casing, the output end of which is sealed and comprises a sump for lubrication of the gear train (see Fig. 4). The selsyn motor (B.T.H. Type 1406) and a 2-in. coincidence magslip are housed in the main structure behind the gear compartment. The output shaft is integral with the output gear and is coupled at one end to the multi-position phasing coupling and at the other to the 2-in coincidence magslip. This magslip and all others throughout the system are Muirhead standard types.

An error meter (microammeter) is mounted adjacent to the magslip which is used for the initial phasing of this instrument to the reference magslip in the master gearbox. Adjustment for this purpose is provided by a pinion meshing with the tooth rack on the 2-in. magslip casing.

The slave gearboxes are housed in a gallery positioned round the top of the reactor, the drive shaft passing through the concrete shield.

Master Gearbox. The master gearbox is situated in the reactor control room and is the means by which the operator can operate the coarse control system. It consists essentially of electric motors driving the master selsyn (B.T.H. Type SJV1813) through a compound epicyclic gear train designed to give the required speed of operation of the control arms, and a counting gear train driving the 3-in. coincidence magslip and two 2-in. transmitter magslips.

The motors are 1/33-h.p. Evershed and Vignoles Type FE17/A, 50-V three-phase, running at a synchronous speed of 3,000 r.p.m. They operate four different drive systems: (a) Fast-in Drive, which employs two motors in tandem driving through a worm and worm-wheel reduction and results in the coarse control arms being driven down from the horizontal through an angle of 56° in 5 minutes; (b) Slow-in Drive, employing one motor driving through a worm and worm-wheel reduction and an epicyclic reduction to drive the coarse control arms from horizontal through 56° in 25 minutes; (c) Slow-out Drive, which is similar to (b) above, except in the reverse direction; (d) Super Fast-in Drive, which utilizes the fast-in drive and the slow-in drive together to move the arm down from the horizontal through 56° in 4.17 minutes. The motors drive through overdrive couplings which guard against backward running, which might result from incorrect electrical connection or from one unit motorizing another.

An overload clutch is positioned between the epicyclic gear output shaft and the 1:1 bevel gearing which drives the six-channel selsyn. The clutch is set to slip at approximately 66 oz. in. torque which limits the maximum torque which can be converted into electrical energy at the transmitter selsyn and relayed to the receiver selsyn in the slave gearboxes where it is reconverted to a torque of some 11 oz. in. at the input shaft.

The branch counting train of spur gears operates:

(a) The 3-in. coincidence transmitting magslip which feeds into the error-detection amplifier in conjunction with the feed from the 2-in. transmitting magslips in each slave gearbox. This arrangement forms the system which operates the trip relays.

(b) Two 2-in. transmitter magslips which feed information to two 2-in. receiver magslips on the control panel which provide fine and coarse indication of control arm position. The indicator dials are calibrated in 1/100th and 1-degree steps respectively.

(c) Limit switches which cut out the drive motors when the arms approach horizontal and the "fully in" positions.

(d) A mechanical screw stop which operates in the case of failure of the limit switch.

(e) A helical potentiometer which relays its voltage variation to a recorder in the control panel which provides a permanent record of coarse control arm positions.

The components of the master gearbox are mounted on top of and underneath a centrally disposed plate in a cast light-alloy box. The gears are underneath the plate and run in an oil-filled sump which forms the bottom of the box. The selsyn drive motors, magslips and other electrical equipment are mounted on top of the plate in the region free from oil. The cover of the box is fitted with a lock, the key to which is the same as that which is necessary to unlock the covers on the coarse control arms. Removal of the key for this purpose cannot be achieved without shutting-down the reactor. The whole gearbox is mounted behind the control panel on telescopic bearers which enable it to be withdrawn for maintenance and adjustment. Fig. 5 shows the master gearbox with cover removed.

Fine Control Group

The fine control group provides the rapid control of small changes in reactivity due to burn-up of the fuel, accumulation of fission products which act as poisons and variations due to changes in experiments being carried out on the reactor. It consists of one fine control rod operated by a fine control gearbox, control being established via a closed-loop servo system, which has been developed by Elliott Bros. in collaboration with A.E.R.E., Harwell. A selector switch is provided in the control room which enables the operator to operate the fine control either manually or automatically.

Fine Control Rod. The fine control rod (Fig. 6) is housed in a sealed aluminium tube of welded construction which extends from the top to the bottom of the reactor aluminium tank. The cadmium absorber, in the form of sheet wrapped into a cylinder 24 in. long (area 255 cm^2), is contained between two stainless-steel tubes. This assembly is welded to the bottom of a stainless-steel screw. The screw, which is irreversible, is driven by a phosphor-bronze nut attached to a long drive tube operated by the drive shaft from the fine control gearbox via a 4:1 worm reduction gear situated in a cast aluminium alloy housing at the top end of the assembly.

When fully withdrawn, the rod is positioned about 6 in. above the reactor core and travels 24 in. (61 cm) downwards, when it is some 18 in. inside the core. This means that the control rod itself is always in a zone of considerable reactivity, resulting in the generation of heat which would result in an unacceptably high temperature unless the rod were cooled. Cooling is achieved by the circulation of demineralized light water through the centre of the rod and back through the annulus between the rod and its stainless-steel covering thimble. Wire-wound edge-type filter units are provided in the light water flow and return, to remove small solid impurities which may be contained in the system. The cooling water becomes highly radioactive and precautions are necessary to shield it adequately. The activity of the water also precludes the use of many materials normally used for sealing. Synthetic rubber of the neoprene type has been found to be reasonably satisfactory for this purpose.

Fine Control Gearbox. This unit includes a two-phase a.c. servo-motor with feed-back generator which has been developed by Elliott Bros Ltd. driving an output shaft terminating in a phasing coupling via an overload clutch. A monitoring and counting gear train driving a magslip provides remote indication in the control room of the position of the fine control rod position. Local indication is given by a pointer moving over a dial in the gearbox, visible through a Perspex window. Mechanical and electrical limits are provided together with a means for absorbing motor inertia in the event of a limit switch failure. The

equipment is housed in a cast aluminium alloy box which is provided with attachment points to suspend it from the appropriate beam in the reactor gallery (Fig. 7).

The normal running speed of the motor is 1,200 r.p.m. (1,500 r.p.m. maximum), so an oil pump is provided to pump oil from the sump to lubricate the moving parts. Considerable attention has been given in the design to keep the inertia of the moving parts of the gearbox, drive shaft and control-rod operating mechanism to a minimum, as the estimates of inertia and friction have proved to be optimistic in practice, resulting in the available motor torque not being excessive.

Safety Rod Group

The requirement for the provision of emergency shut-down is met primarily by the coarse control arms. However, additional cadmium absorber is provided in two safety rods to control an additional 3% in reactivity. When the reactor is running normally these safety rods are in the "out" position. Whenever a "trip" shut-down occurs the safety rods, which are suspended by means of steel cables, are allowed to fall under gravity to the "in" position. Push-button control allows the operator to release the safety rods at his discretion.

A safety rod gearbox is provided with each safety rod to wind the rod back to the "out" position, and includes a device to absorb the kinetic energy of the falling rod during the later stage of its fall.

The Safety Rod. Like the fine control rod, each safety rod is housed in a welded pure-aluminium thimble tube which extends down through the reactor core. As the safety rods are normally in the "out" position, and when they are "in" the reactor is shut-down, there is little heat generated in the absorber; it has therefore not been necessary to provide cooling for the safety rods as in the case of the fine control rod.

A safety rod consists of a stainless-steel tube, containing 990 cm^2 of cadmium absorber in the form of a sheet wrapped into a cylinder 30 in. long. The rod terminates at the bottom end with an aluminium alloy nose piece which will deform and absorb the shock when it hits a steel anvil provided in the plug at the bottom of the aluminium thimble tube. This will only occur in the unlikely event of a cable breaking, and the collapsible nose and steel anvil have been developed so that no deformation or damage is caused to the thimble tube.

The operating cable passes through a shield plug out of the reactor, over a pulley and thence to the safety gearbox. The safety rods are situated on opposite sides of the reactor and the safety gearboxes are housed in the reactor gallery together with the slave and fine control gearboxes.

Safety Control Gearbox. This is driven by an Evershed and Vignoles motor Type FE.17 as used in the master gearbox, the drive being through a reduction gear train to a drum on which the cable is wound. The arrangement permits the rod to be withdrawn 4 ft. 11 in. from its "in" position in a minimum time of eight minutes.

The drive from the gears is taken through an electro-magnetic clutch which is de-energized when a "trip" occurs or if the operator presses the button which releases the safety rods. When the clutch is de-energized the cable unwinds off the drum as the safety rod falls under gravity until the drum engages a cam, the follower of which is connected by a mechanical linkage to a pair of coil springs. The cam is so designed that on reaching the end of its desired travel, i.e. 4 ft. 11 in., the springs ensure that the rod is brought to rest smoothly.

Limit switches at each end of the safety-rod travel operate appropriate lights in the control room and a potentiometer in each gearbox gives position indication on a dial.

Manufacture

The design of the control system requires considerable accuracy in the manufacture of the components. For example, to meet the back-lash requirements the gears in

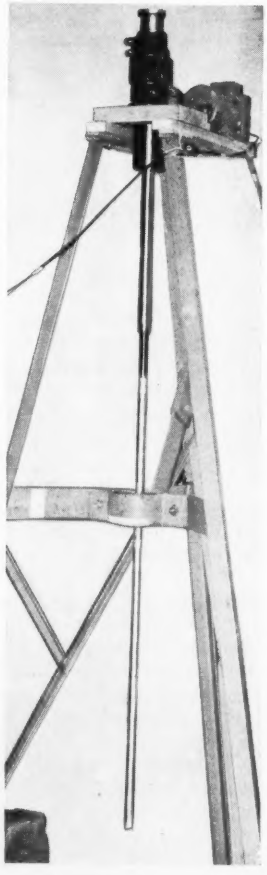


Fig. 6 (right). Fine control rod in test stand, with aluminium housing tube removed.

Fig. 5 (left). Master gearbox, showing selsyn (top left); three of the drive motors (top right); magslips; and limit switches.

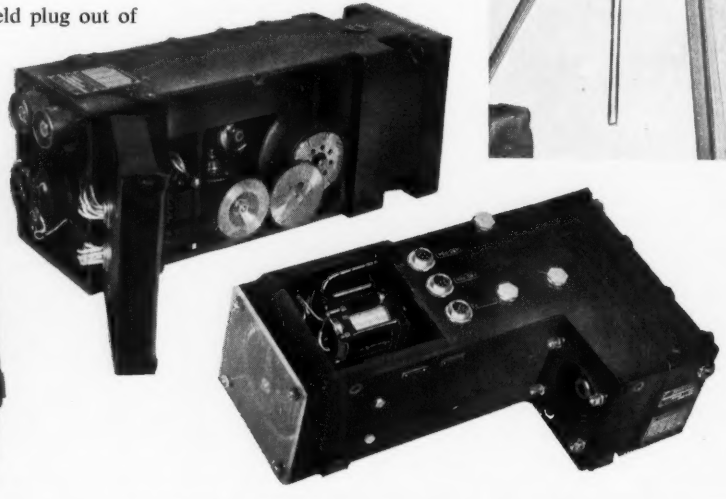


Fig. 7 (right). Fine control gearbox, showing local magslip indicator.
Fig. 8 (above left). Safety gearbox, showing drive motor at left.

the gearboxes are cut to British Standard Specification B.S.436.A2 for precision cut gears. Parts which actually go into the reactor, such as the coarse control arms and the fine and safety rod aluminium tubes, have to be chemically cleaned before welding and assembled under scrupulously clean conditions, the assemblers wearing clean gloves for the purpose. Great care has been taken to ensure that no copper or copper-bearing alloys are used in the parts, or serious corrosion of the aluminium reactor tank might well result. No oil or grease is permitted on parts which are subjected to intense radiation. The roller bearings on the coarse control arm blades themselves are lubricated by the heavy-water vapour only.

The casting of the heavy concrete, made with Portland cement and iron shot, has to be carried out on a vibrating table to ensure uniformity. A test block was cast from each mix and sent to Harwell for density check and measurement of shielding properties.

Testing of the System and Components

The inspection of the equipment was delegated to the company's A.I.D. approved inspection department, although throughout manufacture and test A.E.R.E. engineers paid frequent visits to the works. A prototype coarse control arm was manufactured first, and subjected to several months' testing by A.E.R.E. in a specially designed test rig in which the reactor operation was simulated as closely as possible, except that demineralized light water was used instead of heavy water.

As a result of these tests, certain design changes were made which were embodied in the equipment manufactured for installation in the E.443 reactor. The prototype coarse control arm was subsequently modified to make it suitable for use as a spare. The bearings for the coarse control arm were also given protracted tests under representative conditions in a rig at Harwell.

Individual items such as gearboxes, were run a considerable time, and were then stripped down and carefully examined for evidence of wear and increased backlash. The coarse control system as a whole was tested for several days on the special test rig at Wolverhampton (Fig. 9). These tests included repeated free drops in air from horizontal to the mechanical stop. Parts such as the arrestor ring springs, were then carefully examined.

The fine control rod was run for many hours and, among other modifications made as the result of these tests, the cooling-water sealing arrangements were improved. The safety rod/safety gearbox system was also tested thoroughly and after initial development the rods were dropped and wound up again many times to prove the reliability of the energy-absorption system.

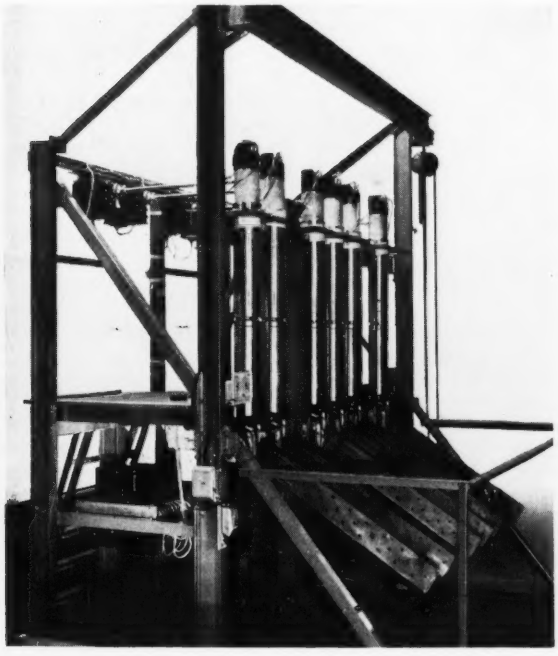


Fig. 9. Coarse control system on test rig.

Système de Contrôle pour le Réacteur DIDO

Le système de contrôle du DIDO est divisé en trois groupes principaux—le groupe de fermeture oblique pour contrôle grossier, le groupe de contrôle ou réglage fin, et le groupe à tige de sécurité. Le groupe de contrôle grossier consiste en six éléments identiques qui consistent en tiges cylindriques contenant le mécanisme de fonctionnement se terminant en pales du genre de bras de signalisation. Ces pales sont fabriquées en acier au cadmium de 2 mm. scellées dans une feuille d'acier inoxydable de 0,91 mm. et soudées à un pivot en acier inoxydable.

Une tige de contrôle fin suit une petite variation de la réactivité. Elle est en cadmium sous forme d'un cylindre creux situé dans un tube continu en aluminium dans le réservoir du réacteur, de l'eau déminéralisée y étant faite passer pour le refroidissement.

Deux tiges de sécurité sont prévues avec une réactivité négative additionelle de 3%. Elles sont situés dans des tubes d'aluminium traversant le noyau du réacteur.

System der Regulierung des Reaktors DIDO

Das Regulierungs-System DIDO ist in drei Hauptgruppen unterteilt—Grob-Regulierung mittels einer Gruppe von schrägen Abschalt Organen—Fein-Regulierung oder Steuer-Gruppe—Gruppe von Sicherheits Stangen. Die Grob-Regulierung ist aus sechs gleichen Einheiten zusammengesetzt, die die Gestalt von zylindrischen Stangen besitzen, an welchen der arbeitende Mechanismus untergebracht ist, der unten Scheiban hat nach Art eines Signalarms. Diese Scheiben sind aus 2 mm starkem Cadmium-Stahl gemacht, die in 0,91 mm dicken Hülsen aus rostfreien Stahlblechen eingeschlossen sind und an Drehzapfen aus rostfreiem Stahl angeschweisst werden.

Eine einzige Stange ist für die Feinregulierung vorgesehen, die auf geringe Verschiedenheiten in der Reaktivität anspricht. Diese ist aus Cadmium und hat die Gestalt eines hohlen Zylinders, der in einem keine Unterbrechung aufweisenden Aluminium Rohr im Reaktor Tank sitzt; von Mineralien freies Wasser zirkuliert durch das Rohr zum Zwecke der Kühlung.

Zwei Sicherheits-Stangen sind vorgesehen für eine zusätzliche negative Reaktivität von 3%. Sie sind in Aluminium Rohren angeordnet, die sich durch den Reaktor Kern erstrecken.

Sistema de Control del Reactor DIDO

El sistema de control de DIDO se divide en tres grupos principales, grupo de cierre oblícuo de control basto, control fino o grupo regulador y grupo de varilla de seguridad. El control basto es un grupo de seis unidades idénticas que toman la forma de varilla cilíndricas que contienen el mecanismo operador que termina en paletas del tipo de brazo de señales. Estas paletas están hechas de acero cadmio de 2 mm. selladas en planchuela de acero inoxidable de 0.91 mm. y soldadas a un pivote de acero inoxidable también.

Una sola varilla de control fino sigue las pequeñas variaciones que ocurren en reactividad. Esta es de cadmio en forma de un cilindro hueco colocado en un tubo continuo de aluminio en el tanque del reactor, por el cual circula agua desmineralizada para enfriarlo.

También se proveen dos varillas de seguridad con una reactividad negativa adicional del 3%. Van colocados en tubos de aluminio que se extienden a través del núcleo del reactor.

Atomic Energy in Eastern Europe

by
J. F. CALOR

PART 2—CZECHOSLOVAKIA

Developments date mainly from 1955 when the foundations of a large scale nuclear power programme were laid. An ambitious programme, based on the home production of uranium and heavy water calls for 3,000 MW installed capacity by 1970, but may be delayed by lack of skilled personnel

CZECHOSLOVAK nuclear research began in 1945 when a laboratory of nuclear physics was set up, attached to the Czechoslovak Academy of Sciences. Later, the Charles University in Prague founded a nuclear physics department and the Academy of Sciences set up a special department for radiochemistry and nuclear physics. Basic research was mainly into the quantum theory and the structure of matter, and the first conference of nuclear physicists was held at Liblice in September, 1953. Progress was also made in reactor theory, and this is illustrated by the fact that in 1955 two research workers, Kvehn and Kment, were granted Czechoslovak patents for a reactor design in which lithium nuclei, stripped of their electrons and bombarded with protons, change into alpha particles. Preparations were also started for building a small research reactor for experiments with uranium, graphite and heavy water but, owing to shortage of skilled personnel, nothing came of it.

In 1955 Czechoslovakia supplied three of the vice-chairmen of the Geneva atomic conference. Seven papers were entered and three of them read: by Dr. Sevcik on Czechoslovak atomic needs; by Eng. Simane on the use of isotopes in Czechoslovakia; and by Trlifaj on theoretical physics. Of more importance for Czechoslovakia was the information gained at the conference.

Realizing that up till then the development of nuclear energy had not been commensurate with the needs of the country, the Government, in 1955, took measures to lay the foundations for a large-scale nuclear development programme. All activities connected with the peaceful use of atomic energy were put in the charge of a special government committee. The Nuclear Physics Institute was set up and a long-term programme for nuclear power drafted.

The Institute is now pursuing basic and applied research in nuclear physics, chemistry and power engineering, it gives post-graduate scientific training and is to produce radio-isotopes. New premises are now being built in Prague and a research reactor from Russia—similar to that at Warsaw—is now being assembled on this site and is expected to be completed soon. In the building of the premises, "lessons learnt at Harwell"[1] are being applied. The U.S.S.R. is also supplying Czechoslovakia with a 25-MeV cyclotron.

In Slovakia, a special committee of the Slovak Academy of Sciences is at present in charge of nuclear studies, pending the establishment of a research institute. Slovakia's largest nuclear physics establishment will for the time being be the cosmic-ray laboratory now being erected in the Tatra Mountains, on the Lomnicky Stit. It is claimed that only two other European observatories, those on the Jungfrau in Switzerland and on the Pic du Midi in the Pyrenees, will be able to match its facilities. Czechoslovak and Polish scientists are now working there on the measurement of the proportion of electrons and protons in big falls of cosmic radiation.

There are several parallels between the British and the Czechoslovak nuclear power programmes. Both countries are highly industrialized and both have a large supply of skilled man-power. In both countries coal-mining will soon be unable to satisfy the rapidly growing energy requirements, and were it not for the advent of nuclear power both would have had to divert increasing portions of their foreign currency earnings to paying for imported coal.

As in Britain, the Czechoslovak nuclear power programme appears to have taken shape in 1954 and 1955. The study of Czechoslovakia's demand for electric power, rising at the rapid rate of 10-12% per annum, showed planners that by 1965 their country's economy would call for 40-45 thousand million units and by 1975 80-100 thousand million units of electric power. They concluded that beyond 1965 the coal-mining industry, already contending with chronic man-power shortages and numerous other difficulties, could not be relied upon to meet the annual increment in power consumption, and that, in view of the country's rich uranium reserves, nuclear power would increasingly have to become the economy's key power source.

Ambitious Power Plans

According to present plans, nuclear power is to take over the full increase in electric power consumption between 1965 and 1975, and partly even replace some worn-out coal-fired plant and exhausted coal seams. The production of nuclear power is to grow to such an extent that, in 1970, one-third of all electric power output is to come from atomic plants; these would then produce 20 thousand million units, and double or treble that amount in 1975. The vastness of this task can only be judged by reference to the British provisional plans for the same period: the programme for Britain, a country with a population nearly four times the size of Czechoslovakia's, is only about double that for Czechoslovakia.

The foundations for these ambitious projects are to be laid in the five years between 1956 and 1960. An experimental nuclear power station of not less than 150 MW capacity is scheduled to be put into operation in 1960. Designs for the building of other nuclear power plants are to be prepared and the construction of a plant for uranium processing and for heavy-water production is to be started.

Design work for the 150-MW station began last spring in the Soviet Union, with the participation of Czechoslovak designers and technicians. Construction of the plant at the chosen site near Banska Bystrica is to begin in 1957. Like the majority of the proposed plants, it will be built in the eastern part of the country, in Slovakia, which at present is in greater need of electric power than the rest of the country. The power reactor for the first station will be bought from the U.S.S.R.; the equipment for all subsequent plants will be made in Czechoslovakia.

The Jachymov mines, although experiencing man-power shortages, are a good source of uranium but, lacking

isotopic separation facilities and being seemingly unable to obtain enriched uranium from the U.S.S.R., Czechoslovak atomic engineers had no choice but to use natural uranium as the fuel for their first power stations. Unlike Britain, however, they chose heavy water as moderator for their first plant—and presumably for others as well—as a heavy-water factory is included in the development programme. The first series of nuclear plants will be designed to produce not only power but also plutonium. This plutonium will be used as fuel for the second stage of fast breeder reactors.

There is little doubt that the Czechoslovak authorities are giving top priority to developing this new source of energy. The future alone can tell whether these extensive projects can be carried out in the scheduled time without overtaxing the country's resources.

Training

Despite Czechoslovakia's high reputation for industrial skill, the authorities must be worried where the thousands of trained workers and scientists for the nuclear power stations and the supporting industries are to come from. Skilled man-power resources already appear extended to the limit, and the assumption of one of the Czechoslovak delegates to the Geneva conference[2] that sufficient specialists can be recruited fairly quickly from among existing qualified personnel may prove over-optimistic. The plan for the training of the basic minimum of technicians and the long-term programme for training research staff yet remain to be drawn up.

Undergraduate training of nuclear specialists is now concentrated at the Nuclear Physics Faculty (head: Prof. Petrzilka) of the Charles University in Prague. The Faculty has chairs of Radioactivity, Physics and Experimental Physics; last March it enrolled some 180 first-year students. Brno University offers one-year courses in nuclear physics for graduates. A school for nuclear technology has been opened in Prague and will give its trainees four-year courses in reactor technology.

In the autumn of 1955 a group of post-graduate students went to the Soviet Union for three-year courses in nuclear research, and technicians of the Nuclear Physics Institute went for several months' training. Leading Czechoslovak specialists pay frequent visits to the Soviet Union.

Radio-isotopes

The application of radio-isotopes is expected to grow considerably when the country starts manufacturing her own isotopes. The Prague reactor is intended to produce monthly a quantity of radio-cobalt 60 equivalent to 1.5 kg of radium. The present Five-year Plan calls for an intensification of research and a substantial expansion in the use of radiation sources and tracer elements in industry, agriculture and the health services.

In medicine the principal application in recent years has been the treatment of malignant tumours. A clinical method of using radio-phosphorus for polycythæmia and leukæmia has also been developed. Radio-iodine is frequently used for therapy and diagnosis. Isotopes of iodine, sulphur, phosphorus, sulphur and sodium have also been used for investigating the dynamics of shock in living organisms with a view to possible application in surgery.

But although considerable use of isotopes is being made in medicine, the emphasis, as in other Soviet-bloc countries, is on the industrial and agricultural applications. In industry, the principal use since 1953 has been that of cobalt and iridium in the detection of faults in metal. Radio-iridium is used for inspecting seams and welds up to 40 mm thickness, and cobalt for thicknesses over 40 mm, and their use is reported to have significantly improved the quality of welders' work. But shortages of precision measuring instruments are delaying the wider use of isotopes in the metal industry. New methods of controlling the weight of paper are being tested at paper mills. The first 100 "stykloskops"—new instruments for determining the composition of some 2,000 types of metals, including alloys, by spectral analysis—will be built in Czechoslovakia this year.

One important use of isotopes in flood control has been for the measurement of the water equivalent of snow, thereby obtaining accurate advance information on the water level of large rivers.

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[1] Statement by Neuman, Vice-Minister of the Chemical Industry, September, 1955.
[2] Proceedings of the Geneva Conference, August, 1955. Vol. I, P 799.

L'Energie Atomique en Europe Orientale :
2ème partie—Tchécoslovaquie

Les recherches en physique nucléaire ont commencé en 1945 par l'établissement d'un laboratoire dépendant de l'Académie des Sciences Tchécoslovaque. Certains progrès furent effectués dans le domaine des recherches de base mais ce ne fut qu'après la conférence de Genève de 1955 que les choses allèrent de l'avant d'une manière sensible. Cette année-là, l'Institut de Physique Nucléaire fut fondé et les bases d'un programme d'énergie nucléaire à longue échéance furent jetées. Ce programme envisage qu'en 1970 un tiers de l'électricité du pays sera produit dans des génératrices nucléaires. On s'attend à finir la première de ces usines génératrices, dont la capacité ne sera pas inférieure à 150 MW, en 1960, et on prévoit une augmentation de la capacité à 3.000 MW pour 1960.

Le pays possède de riches dépôts d'uranium et des plans ont été tirés pour la construction d'une installation de traitement et la production d'eau lourde.

Atomkraft in Ost Europa
Teil 2—Tschechoslovakei

Atomforschung begann 1945 mit der Einrichtung eines Laboratoriums, das der tschechisch-slowakischen Akademie der Wissenschaften angegliedert wurde. Einiger Fortschritt wurde zwar in grundlegenden Forschungen gemacht, aber erst nach der Konferenz in Genf 1955 kam man wirklich gut voran. In dem Jahr wurde das Institut für Atom-Physik gegründet und ein Atomkraft Programm auf längere Sicht entworfen. Dieses sieht vor, dass bis 1970 ein Drittel der Elektrizität des Landes in Atomkraft-Werken produziert wird. Das erste dieser Werke, das dann nicht weniger als 150 MW erzeugen soll, soll dem Plan nach 1960 vollendet werden, um dann die Kapazität bis auf 3.000 MW bis 1970 zu steigern.

Das Land hat reiche Uran-Lager und Pläne sind vorbereitet worden, sowohl für ein Verarbeitungs-Werk als auch für die Produktion von schwerem Wasser.

Energía Nuclear en Europa Oriental :
Parte 2—Czecho-Eslovaquia

Las investigaciones nucleares comenzaron en 1945, con la instalación de un laboratorio adjunto a la Academia de Ciencias de Czecho-Eslovaquia. Se hizo algún progreso en las investigaciones básicas, pero no fué sino hasta después de la Conferencia de Ginebra de 1955 que se adelantó mucho. En ese ano, se inauguró el Instituto de Física Nuclear y se estableció un programa a plazo largo para energía nuclear. Este programa prevee que por el en año de 1970 una tercera parte de la electricidad del país será generada en instalaciones nucleares. La primera de estas centrales, de no mentos de 150 MW, está programada para ser terminada en 1960, elevándose la capacidad hasta 3.000 MW en 1970.

El país posee ricos yacimientos de uranio y hay planes en mano para la construcción de una instalación de procesado y para la producción de agua pesada.

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A.E.R.E. C/R 1575(3) ... **Selected abstracts: Part 3—Gaseous systems (excluding organic compounds).** March, 1956. *R. W. Clarke.* 59 pp. H.M.S.O., 8s.

A.E.R.E. C/R 1575(4) ... **Selected abstracts: Part 4—Solid systems (excluding organic compounds).** May, 1956. *R. W. Clarke.* 137 pp. H.M.S.O., 17s. 9d.

A.E.R.E. C/R 1575(5) ... **Selected abrstracts: Part 5—Biochemistry and radiobiology (excluding animal studies).** May, 1956. *R. W. Clarke.* 93 pp. H.M.S.O., 12s. 3d.

A.E.R.E. C/R 1575(6) ... **Selected abstracts: Part 6—Miscellaneous.** May, 1956. *R. W. Clarke.* 57 pp. H.M.S.O., 7s 6d.

A.E.R.E. CE/R 1730 ... **A micro-mixer-settler for laboratory continuous counter-current solvent extraction.** July 25, 1955. *L. B. Mullett.* 9 pp.

A.E.R.E. C/M 260 ... **An apparatus for the disposal of fluorine on a laboratory scale.** October, 1955. *G. Long.* 5 pp. H.M.S.O., 1s.

A.E.R.E. Lib./Trans. 606 **A method for the graphical calculation of the number of theoretical plates in an electrolytic plant with exchange towers for the production of heavy water.*** 1955. *D. Dinelli.* 11 pp.

STAGE 3 SYSTEMS

A.E.R.E. RP/M 65 ... **The temperature coefficient of homogeneous power reactor.** November, 1955. *C. C. Horton.* 7 pp.

A.E.R.E. C/M 262 ... **Fission product gases from a homogeneous power reactor.** November, 1955. *P. C. Davidge, C. J. L. Lock.* 17 pp. H.M.S.O., 3s.

A.E.R.E. RP/R 1778 ... **An analysis of critical assembly and kinetics data obtained from the air-spaced plutonium core assembly (core II) of Zephyr.** January 2, 1956. *A. R. Baker, D. D. McVicar.* 13 pp.

A.E.R.E. M/R 1889 ... **Fission-product concentrations and poisoning in a homogeneous reactor with chemical processing.** March 10, 1956. *W. H. L. Porter.* 50 pp.

A.E.R.E. M/R 1950 ... **Estimated concentrations of the heavy elements in a liquid-metal-fuelled reactor with continuous chemical processing.** June, 1956. *W. H. L. Porter.* 43 pp.

A.E.R.E. C/M 278 ... **Mathematics of fission product formation in reactors with circulating fuel.** May, 1956. *C. J. L. Lock.* 18 pp. H.M.S.O., 2s. 9d.

A.E.R.E. M/M 119 ... **Polonium production and decay in a bismuth reactor system.** June, 1956. *W. H. L. Porter.* 6 pp.

A.E.R.E. Lib./Trans. 715 **Principles of fluidization.*** 1952. *W. Brotz.* 50 pp.

A.E.R.E. C/R 1992 ... **The analysis of bismuth-thorium binary alloys.** July, 1956. *A. Bacon, G. W. C. Milner.* 19 pp.

ISOTOPES

A.E.R.E. I/M 39 ... **The separation of Mn 54, Co 56, Co 58, Zn 65 and Nb 95 in a carrier-free state by the use of anion exchange resin.** December, 1955. *C. E. Mellish* 4 pp.

A.E.R.E. I/R 1688 ... **Prompt gamma-rays from neutron capture as a means of oil-well control.** October 26, 1955. *D. B. Smith, G. R. Church.* 12 pp.

A.E.R.E. Inf./Bib. 98 ... **The industrial uses of isotopes. A selected reading list.** March, 1956. 5 pp.

A.E.R.E. I/R 1693 ... **Leak detection in water mains using radio-isotopes.** January, 1956. *S. Jefferson, J. F. Cameron, A. M. Wildblood, J. L. Putman.* 21 pp. H.M.S.O., 4s. 9d.

IGO-AM/W 35 ... ... **The determination of alpha and beta activities in vegetation, roots, seaweed, soil, seabed sludge, seashore sand, silt and river mud.** April 12, 1956. *Chemical Services Department, Windscale.* 4 pp.

IGO-AM/W 37 ... ... **Counting the total alpha activity of granular material at "infinite depth" using an alpha scintillation counter, type 1093.** April 17, 1956. *Chemical Services Department, Windscale.* 4 pp.

A.E.R.E. C/R 1892 ... **The electro-deposition of ruthenium.** March 1, 1956. *A. C. Littlejohn.* 4 pp.

A.E.R.E. Inf./Bib. 101 ... **The use of isotopes in biology and medicine. A selected reading list.** May, 1956. 4 pp.

IGO-AM/W 39 ... ... **The preparation of standards for the determination of alpha and beta activities of granular samples.** June 12, 1956 4 pp.

IGO-AM/W 57 ... ... **Counting iodine-131 in samples of chemically separated iodine.** July 11, 1956. 7 pp.

A.E.R.E. Lib./Trans. 729 **The production and separation of carrier-free radioactive isotopes.*** 1955. *A. N. Murin, V. D. Nefedove, I. A. Yutlandov.* 66 pp.

A.E.R.E. Lib./Trans. 775 **Use of radioactive isotopes for the measurement of gas-flow velocity and for the automatic control of gas flow by the method of "tagged molecules".*** 1956. *N. N. Shymilovskii, L. V. Meltzer.* 6 pp.

A.E.R.E. C/R 1725 ... **The determination of rubidium and cæsium in sodium-potassium alloys and related materials by radioactivation.** September, 1955. *M. J. Cabell, A. Thomas.* 14 pp. H.M.S.O., 2s. 6d.

A.E.R.E. Lib./Trans. 458 **A comparison of the sensitivities of different methods of measurements for radio-carbon.*** 1954. *M. Reinharz, G. Rohringer, E. Broda.* 4 pp.

FISSION PRODUCTS

A.E.R.E. C/R 1861 ... **The temperature distribution in a heated clay block and its application to the problem of fission-product disposal.** February, 1956. *C. B. Amphlett, D. T. Warren.* 9 pp.

A.E.R.E. C/R 1862 ... **The possibility of self-fixation of highly active wastes.** February, 1956. *C. B. Amphlett.* 7 pp.

A.E.R.E. C/R 1870 ... **The separation of rhodium-105 from mixed fission products.** February 1956. *R. B. Chenley, R. G. Osmond, S. G. Perry.* 12 pp. H.M.S.O., 2s.

A.E.R.E. C/R 1686 ... **Fixation of activity in solid form by absorption on soils: Part 1—Firing and leaching tests.** June, 1956. *C. B. Amphlett, D. T. Warren.* 11 pp.

HEALTH

A.E.R.E. EL/R 1753 ... **The rapid detection and continuous monitoring of radioactive contamination on dust in laboratory air.** September 7, 1955. *K. E. G. Perry.* 65 pp.

A.E.R.E. EL/R 1851 ... **The measurement of radioactivity in the human body by NaI-Tl scintillation counters.** February 2, 1956. *R. B. Owen.* 12 pp. H.M.S.O., 2s. 6d.

A.E.R.E. HP/M 89 ... **A portable self-contained air sampler for emergency use.** September 16, 1954. *R. F. Hounam.* 7 pp. H.M.S.O., 1s. 9d.

A.E.R.E. HP/L 23 ... **A short course in radiological protection, by Health Physics Division and Isotope School.** June, 1956. *R. J. Sherwood, ed., H. J. Dunster, ed.* 102 pp. H.M.S.O., 13s. 3d.

EQUIPMENT AND INSTRUMENTS

A.E.R.E. Inf./Bib. 93 ... **Electromagnetic pumps and flowmeters: bibliography.** Third edition. 1955. *M. Greenhill.* 5 pp.

A.E.R.E. Lib./Trans. 618 **Multiple hydrocyclones of the latest type.*** 1955. *H. Trawinski.* 5 pp.

A.E.R.E. Lib./Trans. 605 **The hydrocyclone as an auxiliary apparatus for the refinement of raw materials.*** 1953. *H. Trawinski.* 32 pp.

A.E.R.E. M/M 104 ... **A recording camera for metallography with polarised light.** January 9, 1956. *B. R. Butcher, I. A. McDonald.* 7 pp.

A.E.R.E. CE/R 820 ... **Liquid-metal brushes.** November 30, 1951. *D. A. Watt.* 42 pp. H.M.S.O., 5s. 9d.

A.E.R.E. GP/R 1939 ... **A stabilized negative E.H.T. supply for use with an electron multiplier.** January 12, 1956. *R. Hallett.* 10 pp.

A.E.R.E. GP/M 187 ... **Further electron guns for use in metre-wave high-power triodes.** January 27, 1956. *L. S. Holmes.* 19 pp.

A.E.R.E. GP/R 1855 ... **Compact D.C. power supplies in the 100-KV region.** February 7, 1956. *H. C. Whitby.* 19 pp. H.M.S.O., 4s. 6d.

A.E.R.E. EL/M 42 ... **Corona discharge tube stabilization.** April, 1950. *T. A. J. Jaques.* 17 pp.

A.E.R.E. N/M 76 ... ... **Neutron detectors for the Harwell Fast Chopper.** March 26, 1956. *K. P. Nickolson, J. W. Hall.* 18 pp. H.M.S.O., 2s. 9d.

A.E.R.E. RP/M 72 ... **Design of a large antimony-beryllium neutron source for use with exponential assemblies.** March 7, 1956. *V. S. Crocker, K. J. Henry.* 10 pp. H.M.S.O., 2s.

IGR9R/CA 173 ... ... **Rate of temperature change recorder.** April 16, 1956. *W. Jacques.* 15 pp.

A.E.R.E. Lib./Trans. 656 **Resolving power of scintillation spectrometers.*** 1955. *I. F. Barchuk, E. M. Galkin, M. V. Pasechnik, N. N. Pucherov.* 5 pp.

IGRL-T/R 6 ... ... **The design of an electromagnetic brake.*** December, 1954. *M. A. Panasenkov.* 9 pp.

A.E.R.E. GP/R 1937 ... **A permalloy strip magnetometer for fields of 5 to 120 oersteds.** May, 1956. *D. A. Gray.* 10 pp. H.M.S.O., 2s.

A.E.R.E. CE/M 172 ... **A metal vacuum furnace for the melting of metals by radio-frequency heating.** June, 1956. *F. Roberts, B. T. Bell.* 13 pp.

IGR-R/CA 184 ... ... **Design and development of a variable-flow centrifugal pump for alkaline solutions.** August, 23, 1956. *A. Barker, F. McKay.* 7 pp.

IGR-R/CA 188 ... ... **A fifty-four-channel recorder.** August 22, 1956. *E. Duncombe, W. Jaques.* 17 pp.

A.E.R.E. EL/R 229 ... **Vacuum equipment for the 4-MeV linear electron accelerator.** March 10, 1949. *B. G. Loach.* 51 pp. H.M.S.O., 7s. 6d.

A.E.R.E. ED/R 1856 ... **A.C. liquid-metal pumps for laboratory use.** January 24, 1956. *D. A. Watt.* 33 pp. H.M.S.O., 6s. 3d.

A.E.R.E. X/R 1771 ... **Non-linear effects in alternating gradient synchrotrons.** October, 1955. *P. A. Sturrock.* 41 pp.

A.E.R.E. T/M 128 ... **Focusing in the proton linear accelerator 11.** July, 1955. *Mrs. M. Bell.* 13 pp.

A.E.R.E. C/R 1757 ... **A quartz-fibre ultra microbalance for use inside an evacuated container.** October 7, 1955. *W. P. Hutchinson.* 15 pp.

A.E.R.E. Lib./Trans. 617 **The state of the development and application of hydrocyclones.*** 1955. *F. J. Fontein.* 10 pp.

MISCELLANEOUS

A.E.R.E. C/R 1809 ... **A technique for mounting very small single crystals for X-ray investigations.** December 8, 1955. *E. Wait.* 7 pp.

A.E.R.E. Lib./Trans. 576 **Contributions to the chromatographic contact-print method.*** 1954. *J. Chervet, R. Pierrot.* 16 pp.

A.E.R.E. Lib./Trans. 589 **A gas-bubble chamber, a possible recorder of the elementary process of interaction of ionizing radiation with matter.*** 1955. *G. A. Askar'yan.* 2 pp.

A.E.R.E. Inf./Bib. 97 ... **The United Kingdom atomic energy power programme. A selected reading list.** March, 1956. 4 pp.

A.E.R.E. Inf./Bib. 99 ... **A general introduction to nuclear engineering. A selected reading list.** March, 1956. 2 pp.

A.E.R.E. Lib./M2, Supl. 1 **List of translations issued by the library, May 1 to December 31, 1955.** March, 1956. 6 pp. H.M.S.O., 1s. 6d.

IGRL-1B/R 6 ... ... **Nuclear power engineering; a select and annotated bibliography.** April, 1956. *J. C. Hartas.* 10 pp.

IGR-R/CA 159 ... ... **Effect of eccentricity and whirl on back diffusion in sleeve glands.** December 30, 1955. *M. G. Davies.* 20 pp.

A.E.R.E. Lib./Trans. 711 **Testing chipability by means of the Leyensetter pendulum.*** 1930-1931. *A. Wallichs.* 7 pp.

A.E.R.E. Inf./Bib. 103 ... **Bibliography on the brazing of mild steel.** June, 1956. *G. L. Cooper.* 6 pp. H.M.S.O., 1s. 3d.

Technical Papers and Publications

INSTITUTE OF FUEL
Paper presented on December 5, 1956, at the Institution of Civil Engineers

United Kingdom Fuel and Power *by L. F. Haber, B.Sc. (Econ.), Ph.D. (Imperial Chemical Industries Ltd.)*

In surveying the country's supplies of coal, gas, electricity and fuel oil and future power requirements, the author takes the years 1948-55 as a basis and deals with estimates up to 1980.

Fuel consumption in the U.K., expressed in million tons of coal equivalent, rose from 203 in 1948 to 232 in 1955. Estimated requirements are 258 by 1960, 311 by 1970 and 367 by 1980.

Coal will continue to play a very important role if the future production cannot be quickly, or, indeed, very significantly, increased; further, nuclear energy will not be available on a significant scale before the end of the 1950s. The author shows that the gap between requirements and indigenous supplies, though growing at an alarming rate until 1960, increases more slowly thereafter and by 1980 would appear to settle down to between 30 and 40 million tons of coal equivalent which can be satisfied by oil imports. Any fuel crisis would therefore be acute within the next ten years.

Changes in the pattern of consumption, notably the gradual shift from coal to gas and electricity, and some of the economic problems of the fuel and power industries are described.

JOINT NUCLEAR MARINE PROPULSION PANEL
Paper presented on November 27, 1956, at the joint meeting of Institute of Marine Engineers and the Institution of Naval Architects

Some Safety Considerations of Nuclear Power Reactors *by C. D. Boadle, B.Mech.E. (engineering laboratory, Rolls-Royce Ltd.)*

The paper presented was the first under the auspices of the newly-formed Joint Nuclear Marine Propulsion Panel and was concerned with the more general aspects of the safety of nuclear power reactors—no attempt being made to be specific to the marine side.

Of prime importance in the design of any reactor power system are the safety considerations due, first, to the personnel hazards arising from major accidents and, secondly, to the financial risks associated with any mishaps. In propulsion units, furthermore, such as a ship, failure of a power unit at a critical time would endanger the lives of those dependent upon it. A large number of reactors has already been built for various purposes and the incidence of accidents has been small. The classic accident which is suggested as being typical of potential risks was the Chalk River accident, which took 14 months to repair but was accomplished without any danger to human lives.

The importance of the delayed neutrons following a fission process is emphasized and the simple formula for reactor period against reactivity derived. When the prompt neutrons are sufficient to sustain a chain reaction, the reactor is in a state of prompt criticality, to be avoided at all costs. One main problem associated with control is the excess activity that must be built in, in the clear unpoisoned state, to allow for the burn-up of fuel and the production of neutron-absorbing fission products. This is of particular importance where the reactor must be shut-down and then restarted at any time subsequently, as xenon poisoning particularly is the result of the decay of iodine and rises sharply after shut-down when the neutron flux, the chief instrument of its destruction, is removed. The extent of this poisoning is a function of the neutron flux and it would appear that a maximum flux of 10^{14} n/cm^2-sec. only can be tolerated, as even this implies an excess reactivity to be built in of 2.7% (prompt criticality occurs with an excess reactivity of 0.7% with U 235 as fuel and less with U 233 and Pu 239). From the clean, cold condition, reactivity is further reduced by changes in density of the moderator which may, in turn, affect the neutron spectrum. A large negative temperature coefficient is a highly desirable feature and accounts for the inherent safety of the graphite-moderated, gas-cooled reactor, as in this system the neutron-absorbing properties of the moderator are small. The water-moderated reactor can be inherently unsafe due to the changes in the moderator temperature causing a greater decrease in absorption than in moderation. Proper design, however, can eliminate this feature and experience on BORAX indicated that cavitation and boiling allows this system to be built with complete safety. There is a strong tendency to enclose a reactor system in containment shells, as typified by the Dounreay sphere and the complete enclosure of the Shippingport system. It is probable, however, as more experience is gained, containment of many systems will be considered unnecessary.

In the consideration of the reliability of any control system, coincidental failure of a number of the control units must be provided for at the same time as a failure of coolant flow, failure of power supplies and auxiliaries, etc. However, it is impossible in even a major power excursion to resemble an atomic bomb, but for the reasons previously described the possibility of these excursions must be as remote as it is conceivable to make them.

Meetings to Note

January 3.—Institute of Metals (London section at 17 Belgrave Square): "The Metallurgical Challenge of Nuclear Power", H. K. Hardy.

January 3. — Leeds Metallurgical Society (Leeds University, Chemistry Lecture Theatre): "Some High-temperature Properties of Copper Alloys", J. P. Dennison.

January 4.—Society of Instrument Technology (Fawley Section at Copthorne House): "Position Displacement Meters" (George Kent Ltd.).

January 4.—Institution of Mechanical Engineers: "An Experimental Investigation of the Process of Expanding Boiler Tubes", J. M. Alexander and Professor Hugh Ford.

January 7 *and* 8.—Physical Society (at Queen Mary College): "Conference on Crystal Dynamics".

January 8.—Institution of Chemical Engineers (Geological Society, Burlington House, London, W.1): "Solution of the Equation for Mass Transfer in Plate-type Distillation", H. H. Rosenbrock.

January 8. — Institute of Metals (Oxford section, at the Cadena Cafe, Cornmarket): "Gases in Metals", C. E. Ronsley.

January 8.—Institution of Electrical Engineers: "A Theoretical and Experimental Investigation of Anisotropic-dielectric - loaded Linear Electron Accelerators", R. B. R. Shersby-Harvie, L. B. Mullett, W. Walkinshaw, J. S. Bell and B. G. Loach.

January 11. — Nuclear Engineering Society (Risley branch, in the Little Theatre): "Research Reactors", Dr. J. C. Orkney.

January 16.—Society of Instrument Technology (Newcastle section, at Kings College): "Temperature Measurement by Filled Systems", A. Muir (Negretti and Zambra Ltd.).

January 16.—Manchester Metallurgical Society (Central Library, Manchester): "Physical Chemistry in Extraction Metallurgy", F. D. Richardson.

January 21.—Institute of Metals (Sheffield section at the University Engineering Lecture Theatre): "Research Work in the Department of Metallurgy, University of Sheffield", Professor A. G. Quarrell.

January 22. — Nuclear Engineering Society (Risley branch, Main Hall): "Nuclear Power, Past and Future", Dr. D. V. Dunworth.

January 23.—Society of Instrument Technology (South Wales section, at the Training Centre, Llandarcy Refineries): "Present and Future Trends in Electronic Instrumentation", R. J. Redding (Evershed and Vignoles Ltd.).

January 24. — I.E.E. Mersey and North Wales Centre (joint meeting with North-western branch of I.Mech.E., Liverpool): "The Pressurized-water reactor as a Source of Heat for Steam Power Plants", Professor J. M. Kay and Mr. F. J. Hutchinson.

January 29.—I.E.E. Measurement and Radio sections: "Performance of d.c. Amplifiers with Special Reference to the use of Transistors", K. Kandiah and G. B. B. Chaplin.

INSTITUTION OF MECHANICAL ENGINEERS
Paper presented for publication with written discussion

Effect on the Local Heat-transfer Coefficient in a Pipe on an Abrupt Disturbance of the Fluid Flow: Abrupt Convergence and Divergence of Diameter Ratio 2 : 1 *by A. J. Ede, M.A., B.Sc., C. I. Hislop, B.Sc., Ph.D., and R. Morris, B.Sc.*

A great deal of study has been devoted to the phenomena of heat transfer in pipe flow of what may be termed a continuous nature; that is, relating to pipes which are straight, of uniform diameter and free from any feature tending to disturb the flow. Valves, elbows and similar pipe-work give rise to phenomena of a more or less discontinuous kind. Whilst information is available on the fluid-flow aspects of these phenomena, little is known about heat transfer under such conditions.

This paper details the results of the first stages of a programme of research being carried out at the Mechanical Engineering Research Laboratory, East Kilbride, Glasgow, and deals with the phenomena arising from an abrupt change of section.

The effect of an abrupt convergence, diameter ratio 2:1, on the local heat-transfer coefficient for water flowing in a straight pipe has been determined for Reynolds numbers from 800 to 100,000 in the smaller, 1-in. diameter, pipes. The pipe was heated by the passage of a heavy d.c. current longitudinally in the pipe wall. Heat flux rates varied from 0.02 W to 3.8 W/cm^2 and pipe to water temperature differences from 0.3°C to 8.8°C. The variation in local coefficient, particularly for Reynolds numbers in excess of 10,000, was found to be comparatively small, differing little from that found in the entry regions of pipes under more normal entry conditions.

The effect of an abrupt divergence of diameter ratio 1:2 was also examined under similar conditions for Reynolds numbers from 3,700 to 45,000 in the larger (2-in.) pipe. The variation was considerable, being equivalent to the addition of from 7 to 14 diameters to the length of the pipe.

Personal

Mr. Clifford Evans has been appointed a director of Thos. Firth and John Brown Ltd. Mr. Evans was appointed a local director last January.

Sir Arthur P. M. Fleming, C.B.E., on the occasion of his retirement from the chairmanship of the BEAMA Education Committee, was presented with an engraved silver cigarette box by the Committee. Sir Arthur had been chairman of the Education Committee since its constitution in 1917.

Sir George Briggs has joined the board of Thompson Brothers (Bilston) Ltd. as deputy chairman. Sir George is director of the Brush Group and Thomas Tilling and a member of the Royal Ordnance Factories Board. He is also a consultant to Tube Investments Ltd. and a member of the Government Committee on Steel and Tinplate Redundancies.

Sir Rupert de la Bere, Bart., K.C.V.O., has been elected the first president of the London branch of the Institute of General Managers.

Mr. H. E. F. Taylor has been appointed executive secretary of the Radio Communication and Electronic Engineering Association. Mr. Taylor has recently returned from India, where he had been in business for many years.

Mr. W. O. P. Jones, B.Sc. (Eng.), A.M.I.E.E., has been appointed assistant superintendent, electronics department, of Metropolitan-Vickers Electrical Co. Ltd. He was previously manufacturing engineer in the radio (now electronics) department. **Mr. W. Davies,** B.Sc., has been appointed assistant chief engineer, large steam turbines; **Mr. F. D. Roberts,** Assoc.M.C.T., assistant chief engineer, medium and geared steam turbines; **Mr. G. H. Butterworth,** B.Sc., A.C.G.I., A.M.I.Mech.E., A.M.I.E.E., superintendent, mechanical department, in succession to **Mr. A. C. Annis,** and **Mr. A. D. Clayton,** works manager, and **Mr. A. Cormack,** B.Sc. (Eng.), assistant superintendent, both at Germiston Works.

Mr. E. G. Thompson has relinquished his post of public relations officer of Baird and Tatlock (London) Ltd. and has become technical sales manager of the company. He is succeeded as P.R.O. by **Mr. D. J. Wykes.**

Mr. W. O. P. Jones.

Mr. H. S. Loebl, a financial director of Laurence Scott and Electromotors Ltd. since 1935, is to retire from the board. Mr. Loebl will be succeeded by **Mr. P. M. Tapscott,** who was until recently financial officer of the Friends' Provident and Century Life Office.

Dr. A. Roux is to plan a detailed research programme for promoting the peaceful use of atomic energy in South Africa.

Mr. D. G. Dodds, LL.B., has been appointed chief industrial relations officer of the Central Electricity Authority. He was formerly secretary of the South Wales Electricity Board. **Mr. F. W. Smith,** C.M.G., M.C., chief contracts officer to the Authority, has retired, but will act, on a part-time basis, as contracts adviser.

Dr. T. B. Taylor, a theoretical physicist, formerly with Los Alamos Scientific Laboratory, **Dr. H. A. Thomas,** a physicist who was chief of the Radio Standards Division of the National Bureau of Standards, and **Dr. Lloyd Zumwalt,** a physical chemist who during the past year was operations vice-president of Nuclear Science and Engineering Corporation, have been appointed to the staff of the John Jay Hopkins Laboratory for Pure and Applied Science.

Allen B. Du Mont, Jr., has been appointed assistant division manager of the receiver division at Allen B. Du Mont Laboratories Inc.

Mr. W. C. Morgan, commercial manager of E.M.I. Electronics Ltd., has been appointed engineering director of the company. He will remain in charge of contract sales and for the present will continue, jointly with the managing director, to be responsible for the company's general sales activities.

Mr. W. K. G. Allen (W. H. Allen, Sons and Co. Ltd.), president of the British Engineers' Association, has been elected chairman of the newly-formed Nuclear Energy Trade Associations' Conference which has been established to provide a permanent means of liaison on matters relating to nuclear energy and associated developments.

The Rt. Hon. Lord Coleraine (chairman), **Mr. Harry Fothergill,** a director of Richardsons Westgarth and Co. Ltd., **Mr. J. Mayer,** joint managing director of International Combustion (Holdings) Ltd., and **Mr. J. V. Daniel,** managing director of Crompton Parkinson Ltd., have been appointed to the board of the newly-formed atomic group which will operate through a joint company, Atomic Power Constructions Ltd.

Mr. L. A. Woodhead, director and general manager of Cossor Instruments Ltd., was elected chairman of the Electrical and Electronics Section of the Scientific Instrument Manufacturers Association. **Mr. A. E. Evans,** managing director of Evans Electro-selenium Ltd., was elected vice-chairman.

Sir Christopher Hinton has been awarded the Exner medal for outstanding services to science. The medal was founded 35 years ago in honour of a former president of the Austrian Trade Association.

Lord Chandos has been installed as the first president of the Manchester College of Science and Technology.

Professor Wilfred Murgatroyd, Professor of Nuclear Engineering in Queen Mary College, London University, is visiting Peru, under the auspices of the British Council and at the invitation of the Peruvian authorities, to give a series of lectures on nuclear engineering to scientists and engineers.

He will also be available for consultation with the Peruvian Atomic Energy Commission which has recently been established.

OBITUARY

It is with very deep regret that we have to record the death of **Mr. H. J. F. Gourley,** senior partner of Binnie, Deacon and Gourley, consulting engineers, on December 18. Acknowledged as one of the country's foremost water engineers, Mr. Gourley had been elected President of the Institution of Civil Engineers only six weeks before his death.

World News

The Irish Minister of Industry and Commerce, Mr. W. H. Norton, visiting the General Electric Co.'s atomic energy department at Erith. With him are (left) Mr. M. F. McCourt, of Irish Electricity, and (right) Mr. R. N. Millar, manager of G.E.C.'s atomic energy department.

INTERNATIONAL

The Euratom Treaty for a six-nation customs-free common market and the Euratom atomic pool will be signed on January 15, according to M. Paul Henri Spaak, Belgian Foreign Minister.

The O.E.E.C. Steering Committee held its first meeting in Paris on November 9, its main task being to draw up terms of reference for the study group on the construction of a joint plant for the chemical processing of irradiated fuels.

UNITED KINGDOM

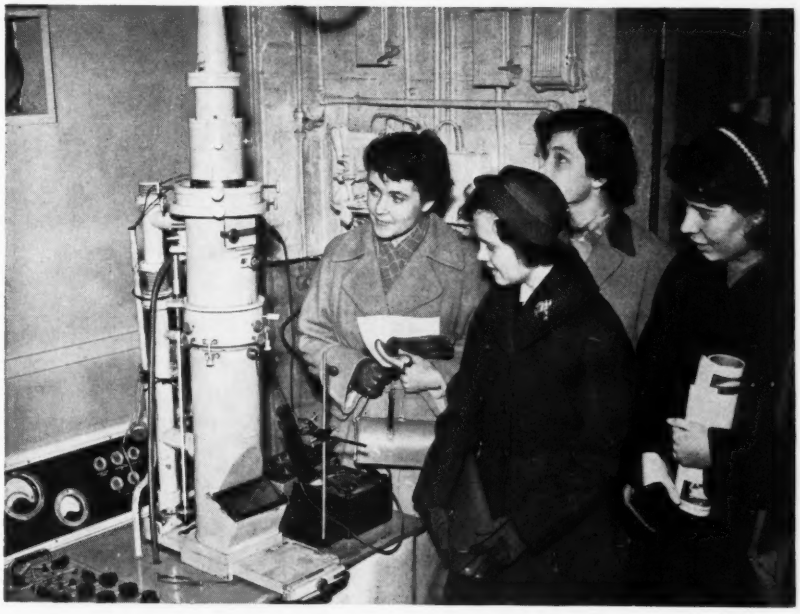
A nuclear graphite project was announced just after our December, 1956, issue had gone to press. It is to be built on Tyneside by the Anglo-Great Lakes Corporation Ltd., a new company comprising the Great Lakes Carbon Corporation of New York and four members of the Nuclear Power Plant Company, viz. C. A. Parsons and Co. Ltd., A. Reyrolle and Co. Ltd., Clarke, Chapman and Co. Ltd., and Sir Robert McAlpine and Sons. Construction of the new plant is expected to start early this year, and the estimated cost has been quoted as £6 million.

North of Scotland H.E.B. Reports that the North of Scotland Hydro-Electric Board has been investigating sites for a nuclear station are not significant, according to the Scottish Amalgamated Trade News Agency, who state that the Board is merely making trial borings to determine the nature of the subsoil.

The second reactor at Calder Hall has been made critical, some three weeks ahead of the scheduled date.

A zero-energy research reactor has been ordered by Rolls-Royce Ltd. from Head Wrightson Processes Ltd. It is believed to be of the light-water-moderated type and connected with the naval propulsion research programme.

Harwell Reactor School is to run a special six-week course from June 3 to July 12 entirely separate from the standard fourteen-week course. The special course should appeal to those of degree standard whose interest lies in the manufacture of ancillary equipment rather than in overall reactor design. In addition to the basic physics and engineering of reactors, metallurgy, shielding and health physics are included. Sixty places will be available and application forms can be obtained from the Reactor School, A.E.R.E., Harwell. Selection will be made at the beginning of March.



Science mistresses from Lancashire and Cheshire schools on a visit to the Metro-Vick research laboratories.

Price increase for nickel to £600 per ton has been announced by the Mond Nickel Co. Ltd.

AUSTRALIA

Damage amounting to £200,000 was caused at the offices and stores of a uranium treatment plant near Mary Kathleen, according to a Reuter message from Brisbane.

Shipping difficulties regarding supplies of sulphur delayed by dock disputes may cause the uranium treatment plant at Rum Jungle to close down early in January, according to a *Times* correspondent from Darwin.

The linear accelerator unit at the Sir Peter McCallum Institute was officially opened in early December by the Minister of Health, Victoria State. The accelerator is a 4-MeV Metrovick unit.

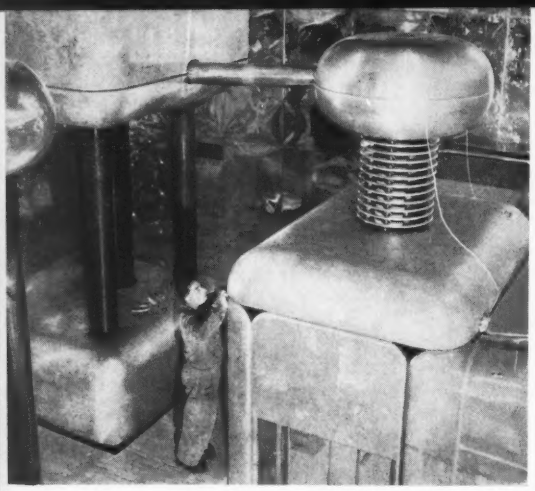
An Industrial Isotopes Exhibition is being organized by the Australian A.E.C. and will open on January 29 in Sydney and in Melbourne on February 18.

AUSTRIA

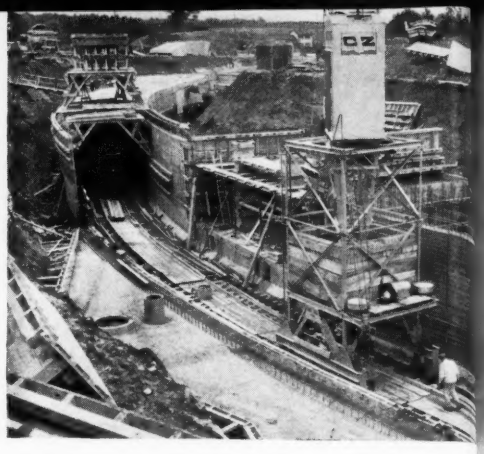
Tenders are to be invited for Austria's first reactor, it has been announced by the Austrian Study Society for Atomic Energy Research. This organization is jointly owned by the Austrian Government and more than 50 of the larger Austrian industrial enterprises.

BELGIUM

A two-day symposium on power reactors for Belgium has been held at Mol, jointly sponsored by the U.S.A.E.C. and the Centre d'Etudes pour les Appli-



(Left) Part of the 500-kV Cockroft-Walton generator for the CERN proto-synchrotron at Geneva. (*United Nations photo.*)



(Right) Construction of the ring building for the CERN proto-synchrotron at Geneva. (*United Nations photo.*)

cations de L'Energie Nucleaire, acting for the Belgian Government. This meeting represented part of the implementation of the agreement between Belgium and the United States. Preceding this conference was a three-day unclassified meeting in Brussels, sponsored by the Atomic Industrial Forum of New York City, of which Belgium is a member. Following this conference, it was announced that a Belgian team would shortly visit the United States to select a power reactor, the actual construction being by Belgian companies. It has also been announced that a materials-testing reactor is to be built under the same terms. This, it is stated, will be more advanced than those of the same type already built in the United States.

CANADA

Two new nickel mines, the Thompson and the Moak, are to be opened in the Mystery-Moak Lakes area of Northern Manitoba by the International Nickel Co. of Canada Ltd. as part of a project that is expected to cost $175 million and will be the largest single nickel-producing operation in the world, next to the well-known Sudbury mines. It is anticipated that when the project is complete, in about four years time, it will increase Inco's production of nickel by some 50%.

The Hamilton College research reactor announced in *Nuclear Engineering* for December is to be of the swimming-pool type, and is to be designed and built by A.M.F. Atomics (Canada) Ltd. This company, incidentally, was awarded the first long-term private industry contract for fuel-element fabrication for Atomic Energy of Canada Ltd.

Eldorado Mining and Refining Co., the Crown-owned organization that is the sole purchaser for all uranium ore in Canada, has extended its "premium" contracts for one year to those producers who will not be able to get five years' full production in by March, 1962, the original date specified, and would not, therefore, be able to amortize their pre-production and capital expenditure costs.

By mid-1957 Canada will be the world's largest producer of uranium, according to a statement made by Mr. F. R. Joubin in Montreal. The U.S. and South America would tie for second place, with the Belgian Congo and Australia third and fourth respectively. Canada's potential production would be worth between 345 and 400 million dollars annually, it was estimated. The Federal Government has since estimated the known reserves of uranium ore as 225 million tons.

EUROPE

The fourth annual report of the Dutch - Norwegian Joint Establishment for Nuclear Energy Research, covering the year ending June 30, 1955, has recently been published.

FRANCE

An information conference in Paris is to be held in April for the benefit of European industrial executives. Organized by the European Productivity Agency in co-operation with the O.E.E.C. Nuclear Energy Secretariat, it aims to give information on nuclear techniques, economic prospects and new problems arising in the metallurgical, chemical and mechanical industries. Main reports will deal with the first nuclear stations, costs, special materials, the status of national programmes and international action in the nuclear energy field.

GERMANY

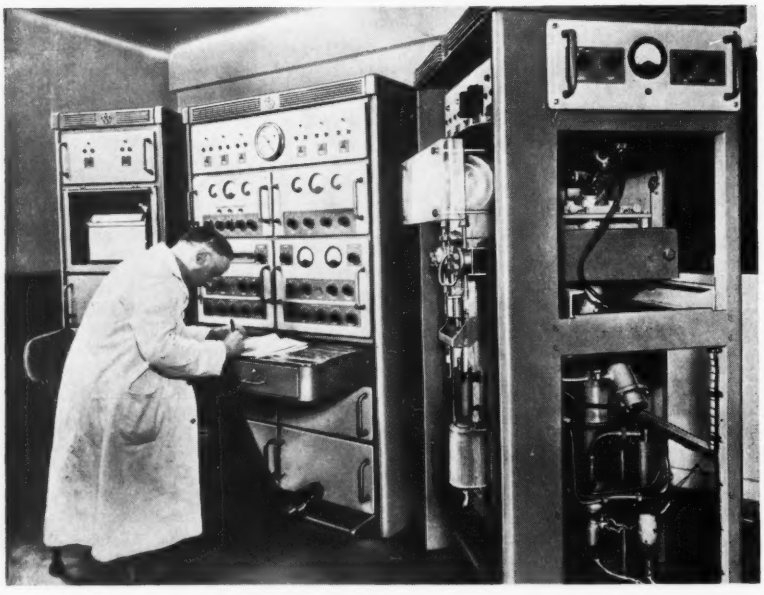
The North Rhine Westphalian Parliament has requested the State Government to order a DIDO reactor in Britain for an atomic research institute to be set up near Düsseldorf in the next two years. It will be recalled that a small reactor of the Merlin type is already on order.

An "atomic locomotive" project is reported to be under way by the West German Railways. The reactor is said to be of the gas-cooled type, and the estimated weight 175 tons, producing some 5,900 h.p., the length being 115 ft. with eight axles. The weight is said to be only a little more than half of that being planned in the United States.

HOLLAND

Isotopes in agricultural research was the main theme of a five-day conference

A Metropolitan-Vickers M.S.2 mass spectrometer in use at Harwell for routine isotopic-abundance measurements and gas analysis.



taking place in mid-December at Wageningen. Opened by Dr. R. A. Silow, the atomic expert of the Food and Agriculture Organization of U.N.O., it was attended by representatives from Ireland, Holland, Belgium, Denmark, Italy, Germany, Israel, Portugal, Spain, Greece, Yugoslavia, Norway, Finland, Austria and Sweden.

ITALY

A heavy-water reactor of the CP 5 (or DIDO) type is to be built in Milan. A contract has been placed by the Comitati Nazionale per le Ricerche Nucleari with the Engineering Division of Vitro Corporation of America for engineering services.

JAPAN

According to a Tokyo report, Japanese engineers have a complete design for a nuclear-powered locomotive. About 100 ft. long, with an estimated weight of 179 tons, the loco uses lithium and beryllium in the reactor. It is stated, however, that "it is not expected to be built in the near future".

Five Japanese scientists launched a three-week airborne search near the end of November to investigate reports of uranium ore in the Kitagami and Abukuma Mountains in Northern Japan.

An agreement has been concluded between Japan and the U.S. for the leasing of 2 kg of U 235. This is for use in the 50-kW boiling-water reactor to be installed by Atomics International at the new research centre 75 miles north-east of Tokyo.

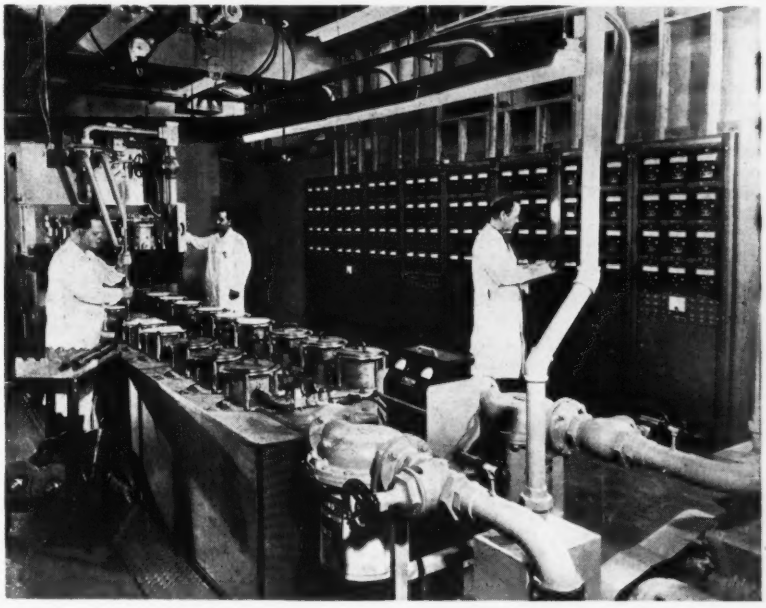
U.S.A.

A feasibility study is being undertaken by E. I. du Pont de Nemours and Co. for the A.E.C. The work, which is intimately concerned with the utilization of natural uranium as a fuel, is being carried out under the existing contract between the du Pont Co. and the A.E.C. for the operation of A.E.C.'s Savannah River plant in South Carolina.

A licence for a low-powered research reactor has been issued by the A.E.C. for a reactor known as AGN 201, to be operated by Aerojet-General Nucleonics at San Ramon, Mexico. Designed to operate at a power level of 100 milliwatts, the reactor is a self-contained facility housed in a steel shell and is said to be a prototype for reactors to be offered for sale to colleges, universities and similar institutions.

A gas-cooled reactor experiment at the National Reactor Testing Station in Idaho is the subject of contract negotiations between the A.E.C. and the Aerojet-General Corporation of Azusa, California, for design, fabrication and operation. The experiment is intended to develop experience and data for the design of military packaged-power reactors and small civilian power plants. More than 20 companies tendered.

Said to be the largest canned pumps in the world, these four units under assembly at the Westinghouse Electric Corporation's works are destined for the Shippingport PWR. Each has a capacity of 18,300 gal./min. at 2,000 p.s.i. and 600°F.



Fuel elements being processed by semi-automatic equipment at one of the Sylvania Electric Products Inc. plants.

Fifty-six patents owned by the U.S. Government have been released by the A.E.C., who will grant royalty-free licences as part of its programme for making non-secret information available to industry. This brings the total so far released to more than 1,000.

Temperatures of 2 million degrees F are said to have been produced in the radiation division of the Naval Research Laboratory. This is believed to be the highest yet produced in the U.S.

Lower costs in uranium processing are expected to develop from a new $40-million plant engineered by the Blaw-Knox Co. (Chemical Plants Division) for the A.E.C. at the Mallinckrodt Chemical Works at Weldon Spring, Missouri.

Berkshire Chemicals Inc. have been acquired by the Vitro Corporation of America. In addition to continuing their own business intact, the new subsidiary will handle sales for the Vitro Manufacturing Co., of Pittsburgh, and Vitro Rare Metals, of Canonsbury, Pa.

Sylvania Electric Products Inc. and Corning Glass Works have announced a proposal for a jointly-owned company for expanded research, development and production activities in the atomic energy field. Sylvania has, of course, some ten years' experience in this field, with particular emphasis on metallurgical research, while Corning is at present engaged in applying high-temperature ceramic techniques to fuel-element construction. Sylvania are, at the moment, undertaking a contract for fuel elements for Atomic Energy of Canada Ltd.

Zirconium production. As a result of recent U.S.A.E.C. contracts NRC Metals Corporation is to build a $3 million production plant near Pensacola.

Orbits in Industry

Thursday, December 13, will long be remembered in the industry as the day when the bag was finally de-catted (or the cat de-bagged) and the official announcement of the allocation of C.E.A. and South Scotland stations put an end to the rumours. For several weeks now, one's entire acquaintance has Known for Certain, Old Boy and now, like racing tipsters, all they have to do is to emphasize how right they were or—more commonly—how nearly right they were. In all the welter of congratulation and confusion (even the date of the release of the information was not really a dead certainty until about 48 hours ahead) the spotlight of publicity seems so far to have left one corner unlighted. The real heroes for this column's money were those who carried out the comparison of the tenders, a small chore that involved six tons of documents. Anyone who has tried to compare half a dozen tenders for supplying and installing one (1) kitchen sink should have some idea of what is involved, and if the C.E.A. stalwarts have not lived for the last few weeks on an exclusive diet of benzedrine and finger-nails, it is due rather to the stoutness of their hearts rather than the facility of their task.

"Heat Barrier"?

Turbines have been in the news lately. Richardson Westgarth have announced that they are to build a 3,000 p.s.i. set for the Margam "B" station of the Steel Co. of Wales Ltd. as a topping unit, discharging after reheating into the existing 600 p.s.i. system.

The C.E.A. has caused a minor sensation by announcing that they are planning a 550-MW set for the 1962 programme. True, this will be a cross-compound set but even one-half of the unit—275 MW—is something that, even a few years ago, would not have been considered a practical proposition. It seems that the limitation in these days is not the courage of the designer—or the purchaser—but what Chesterton referred to as "the rolling English road". (It seems to be pretty well agreed that one particular corner in one particular village settled the maximum size of the Calder heat exchangers, but that, as Kipling said, is another story.)

One interesting feature is that the steam temperature for both schemes is 1,050°F, which means about 1,060°F at the superheater outlet. The C.E.A. points out that this looks like being the upper limit for some years to come, and that in the U.S., although 1,100°F has been specified for some jobs, even more recent ones have returned to 1,050. We seem, in fact, to have reached another nodal point in the advance of steam conditions. Nuclear engineers, in fact, are not the only ones with a red line on their thermometer scale.

That Curtain Again!

The news that the A.E.A. is relaxing many restrictions on information is good hearing. It is even better to see that it is being widely publicized. It would be better still if they could print it in large characters and insist on the publicity manager, managing director and leading executives of every company engaged in the nuclear field having it framed and hanging in his office.

Information is not easy to come by and there may be good, sound commercial reasons for a reluctance to publicity. After all, no organization is in business for the fun of it, and a company may have spent months of effort and a great deal of money on some detail that seems ridiculously simple — after it has been done. And, quite naturally, they will hardly wish to present it to their competitors. This seems fair enough; we all have to live. But, let us be frank about it. Let us not gag all our sub-contractors—and blame it on the A.E.A. until the curtain of silence becomes like the asbestos one lowered (by order of the Lord Chamberlain) . . . "at least once during every performance". Even that one has some information on it.

Further to Above

If a more poetic imagery is required, let us consider the ballet *Petroushka* in which, between two acts, a curtain (or *rideau* if one is a true balletomane) is lowered showing the Wizard with ferocious frown, which seems a reasonably apt parallel. The representation might have frightened us very considerably when we were young, but as we grow older we realize that it is only a formality, a tradition. Something, in fact, to divert us while things are done behind the scenes.

The Cure?

There seems to be a certain amount of hope in the formation (announced elsewhere in this issue) of N.E.T.A.C., the Nuclear Energy Trade Associations' Conference. Methods of publicity vary widely with different industries who have their own trade and technical journals and their own ideas on what they will say and what they will not. The Publicity Committee that N.E.T.A.C. has formed includes many of the best men in their respective industries, and they may be able to break-down a few inhibitions. There must be some happy medium between the sealed-lips attitude of many British companies who have an ingrained dislike of making any statement at all until something has been in full operation for five years and the happy, uninhibited claims frequently put forward by their opposite numbers on the other side of the Atlantic, who are apt to burst into song when a new idea is little more than a twinkle in the designer's eye. N.E.T.A.C. has a hard task before it in making this middle-course attitude generally accepted, but it will be well worth while.

Sales and Research

In the new Electricity Bill, which so far has had an easy passage through the Commons but can still come under a lot of fire over details, one point that will require clarification is the proposal that research facilities should be expanded. One would imagine, in these days of advancing technology, that the central research section would be forced to concentrate on problems of generation. This would seem to cut across, at least in part, the work that has been carried on in the past by the Industrial Group of the U.K.A.E.A.. At the same time, the A.E.A. has announced the setting-up of a Commercial Department with the Industrial Group to handle sales of uranium, plutonium, thorium, graphite and similar materials for the Authority. Such an organization is clearly necessary, now that we have "industrial" nuclear power, but, taking the two proposals together, suggests a change in relative functions of the organizations concerned. No doubt the detailed compositions of the Council and Generating Board would have a considerable influence, but it might be advisable to delegate responsibilities clearly before the Bill is passed.

Tolerance for Tortoises

One of the most acute personal worries at the moment is the lack of reliable information about the maximum permissible radiation for tortoises. The household contains, in addition to humans, various; and cats, sundry; three specimens of the genus which rejoice in the names of Martha, Bertha and the Rollicking Sailor (no prizes are offered for guessing gender or temperament). They are frequently missing and, even in a small garden, are difficult to find, since they possess an ability amounting almost to genius for camouflage. Moreover, it is often important, particularly on evenings when frost threatens, that they should be found. The obvious solution is a small dab of radioactive paint and a Geiger counter, but the translation of this into practical politics presents many difficulties. Can one assume, for example, that tortoiseshell is approximately equivalent to concrete, thickness for thickness? If each tortoise gets the maximum dose permissible, will the radiation from another tortoise increase the dose above tolerance level? (This will be rough on the Sailor, who spends little of his time alone.) Perhaps, after all, it might be simpler to screw an iron nut on to each of them and carry out the search with an induction balance. There must be a way out.

Industrial Notes

A new association known as N.E.T.A.C. (Nuclear Energy Trade Associations' Conference) has been formed with the object of establishing a permanent means of liaison on nuclear energy matters, without restricting the autonomy of the participants. The founder members are the British Chemical Plant Manufacturers' Association; the British Electrical and Allied Manufacturers' Association; the British Engineers' Association; the Scientific Instrument Manufacturers' Association; and the Water-Tube Boilermakers' Association. N.E.T.A.C. has already commenced its task of making British industry's achievements known overseas. In this, it is advised by a publicity committee drawn from British manufacturers and civil engineering contractors. The address is at present that of the British Engineers' Association, 32 Victoria Street, London, S.W.1.

Taylor, Whalley and Spyra, consulting civil engineers, have moved to 24 Harley Street, London, W.1 (telephone LANgham 0172).

Slough Metals Ltd., of Oxford Avenue, Slough Trading Estate, announce that they have appointed F. R. Warren and Co., of 27 St. Nicholas Street, Bristol (telephone Bristol 2-8493), as their West-country technical representatives.

Annals of Physics, a new monthly journal of physics, under the editorship of Philip M. Morse, Professor of Physics, Massachusetts Institute of Technology, has been announced by Academic Press, publishers, New York. Professors Bernard T. Feld (Massachusetts Institute of Technology), Herman Feshback (Massachusetts Institute of Technology) and Richard Wilson (Harvard University) have accepted assistant editorships. They will be advised by an editorial council which includes E. Amaldi, R. F. Bacher, H. A. Bethe, S. Chandrasekhar, E. M. McMillan, L. Nordheim, R. Oppenheimer, R. E. Peirls, L. I. Rabi, F. Seitz, E. P. Wigner and C. Zener.

Volume 1, Number 1, is scheduled for release in April, 1957. Manuscripts should be submitted to the Editor, Department of Physics, Massachusetts Institute of Technology, Cambridge 39, Mass.

Richard Klinger Ltd. announces that its Midlands office is now located at 662 Warwick Road, Solihull (telephone Solihull 4675).

Marconi Instruments Ltd. has transferred its Midland office to 24 The Parade, Leamington Spa.

A.V.B. (Acc-Vickers Babcock (Private) Ltd.) has been formed by Associated Cement Co. Ltd. of Bombay, Vickers Ltd. and Babcock and Wilcox Ltd. A works at Durgapur, West Bengal, is planned for the manufacture of cement-making and mining machinery, gears, pumps, steam generating plant, pressure vessels, cranes and mechanical-handling equipments.

Academic Press Inc. has moved to 111 Fifth Avenue, New York 3, N.Y.

The Institution of Chemical Engineers has moved to 16 Belgrave Square, London, S.W.1 (telephone BELgravia 3647).

British Oxygen Gases Ltd.'s new plant at Brinsworth, near Rotherham, Yorkshire, has been officially opened by the Duke of Devonshire. The new works, one of six new liquid oxygen plants that the company is installing in various parts of the country, has already been in course of construction for three years and will ultimately include an oxygen-compressing station, a dissolved acetylene factory, a garage to accommodate 60 commercial vehicles and a works demonstration and service block, the estimated cost being some £2 million.

Computer Developments Ltd. has been formed as a joint venture between the General Electric Co. Ltd. and the British Tabulating Machine Co.

Mullard Ltd. has moved into new headquarters at Mullard House, Torrington Place, London, W.C.1.

The British Oxygen Co Ltd. and **George Wimpey Ltd.** have formed a jointly-owned subsidiary to be known as British Oxygen Wimpey Ltd., the particular purpose of the new company being the construction of special rocket projects. The headquarters of the organization is at 17 Monck Street, London, S.W.1.

Bennett Tools Ltd. of Redditch, who specialise in precision machinery for spring making, has been acquired by Tube Industries Ltd.

The Du Pont Co. (United Kingdom) Ltd. is to establish a neoprene plant near Londonderry, Northern Ireland. It is expected that construction will commence early in 1957.

Head Wrightson Export Co. Ltd., a subsidiary of the main company, have opened an Indian office at 21 Netaji Subhas Road, Calcutta, 1, which will act as the Indian headquarters for Head Wrightson staff working on the Durgapur steel plant.

The E.M.I. Exhibition

E.M.I. Electronics Ltd., which has now integrated into one unit some of the design, research and production facilities of the main company, staged an exhibition of some of its products at the Royal Hotel at the end of November. The immediate impression on entering the exhibition was of the growing importance of television in industrial processes and the wide range of industrial equipment that is now available. The use of computers has also become more widespread and a steady programme of development is in hand.

Among those instruments on view which have been developed specifically for atomic energy purposes was a wide-band distributed amplifier, type 2B, which has a band width of 50 cycles to 100 megacycles and an overall gain of 12. Input impedance of this model is 75 ohms, and output impedance 200 ohms, with a maximum output of 150 V p.p. continuous range. Output capacity is limited to 5 p.f. for maximum band width. Considerable interest is also being evinced in the atomic energy field for the measuring oscilloscope, type WM2, incorporating a wide-band d.c. amplifier with signal delay. Sensitivities in the Y direction can be adjusted from 75 mm/V to 15 cm/V and extended to 75 cm/mV with a pre-amplifier. The time base measurement is set in 11 ranges from 20 μsec. to 150 μsec., all available with a 6 : 1 expansion. For pulse work this provides a valuable and versatile research instrument.

The range of photomultiplier tubes has been extended recently to include a nominal 1 in.: type 6798. The 5-in. tube, type 6099, with side cathode connection is in full production and mumetal screens are also available. Four types of window are now in use, so that provision can be made for minimizing potassium contamination in the vicinity of the phosphor. The 1-in. model mentioned will undoubtedly find considerable markets in industrial applications where photomultiplier detection can offer considerable advantages over Geiger counters or ionization chambers, and where large phosphors are not of great significance.

We have been asked to make it clear that "Problems of Mechanical Analysis in Reactor Technology" by G. Horvay in our September issue was an abridgment of a lecture delivered by Dr. Horvay at Manchester University. A more complete discussion of the subject is available in Preprint 355 of the Nuclear Engineering Science Congress in Cleveland in 1955.

Reactor Lubrication

The use of molybdenum disulphide as a lubricant for the Calder Hall control mechanisms has already been briefly mentioned in *Nuclear Engineering* for October, p. 285, but space did not then permit a more excursive explanation for its selection. As is generally known, the problem of lubrication in a gas-cooled reactor can become acute, since so many normally-used substances are ruled out by operating conditions. Gamma radiation has a destructive effect upon practically all organic materials such as oils and greases, many becoming useless in a matter of minutes. Experience obtained a few years ago with graphite brushes on the electrical equipment of aircraft showed that, in a really dry atmosphere, brush wear rose to fantastic proportions, the life of a brush being literally reduced from months to minutes, and it was established that a reasonable amount of water vapour in the atmosphere was essential to the lubricating action of graphite.

In a perfectly dry atmosphere, where not even a residual film of moisture can assist, seizure can take place at very light loadings and low speeds, and seizure of parts inside a reactor, particularly in the control-rod mechanism, is not something than can be contemplated lightly.

A considerable amount of test work showed that, in an atmosphere of dry CO_2 at high pressures and temperatures, successful results were obtained with lubricants based on molybdenum disulphide (MoS_2), manufactured by Rocol Ltd., of Ibex House, Minories, London, E.C.3. The final form evolved by this company is known as Molytox, a varnish producing a film of MoS_2. In addition to lubrication, it has a preventive effect against corrosion by CO_2, heat and humidity, and is used for treating replacement equipment and for storage purposes. A further substance has also been developed incorporating a silicone fluid for additional protection.

Official standards for the use of MoS_2 for lubricating purposes are CS 2819, issued by the Ministry of Supply, and MIL-L-7866 (Aer), issued by the U.S. Bureau of Aeronautics. Rocol Ltd. state that these are regarded as minimum requirements and that their product is manufactured to more stringent limits, particularly as regards particle size.

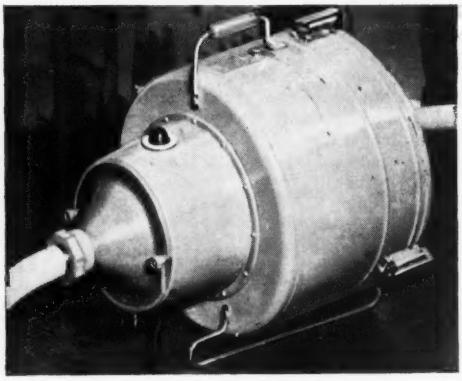
PROPERTIES OF MOLYBDENUM DISULPHIDE

Chemical formula	MoS_2.
Appearance	Blue grey/black lustrous solid or powder.
Hardness	1 to 1.5 (Moh's scale).
Density	4.80.
Crystal form	Hexagonal or trigonal plates.
Cleavage	Perfect basal, yields thin laminæ.
Coefficient of friction	0.04.
Maximum normal working pressure	100,000 lb. per sq. in.
Electrical resistance	High at low potential, but drops as potential rises.
Reaction on heating	Melts, 1,185°C (2,165°F). Sublimes, 450°C (842°F). Decomposes in vacuo, 982°C (1,800°F). Decomposes in nitrogen, 1,427°C (2,600°F).
Reaction at low temperature ...	No action.
Reaction in oxygen	Begins at 399°C (750°F). Marked action at 588°C (1,000°F).
Reaction in gases	Inert, except in fluorine and on heating in chlorine. Reduced in hydrogen.
Reaction in solvents	Inert.
Reaction in water	Inert.
Reaction in acids	Inert, except in aqua regia, hot concentrated sulphuric acid and hot nitric acid.

Radioactive Dust Disposal

The dangers inherent in radioactive dust are well recognized and, wherever radiation is present at any appreciable level, it is the constant aim of all concerned to eliminate dust as far as is humanly pos- The most convenient method of dust removal is obviously the vacuum cleaner, but this, in its standard form, has many disadvantages. It is not sufficient merely to remove dust from its original location. It is essential that there should be no possibility of leakage from the container, and the ordinary cleaner has far too many sources of adhesion and leakage which, negligible for ordinary purposes, are completely useless for the safe collection and disposal of material that may be highly radioactive.

To this end, a special type of cleaner has been developed by Hoover Ltd. at their Perivale works, to the requirements of the A.E.R.E. Intended for cleaning in laboratories or near reactors, more than 100 of these special cleaners have either been supplied or are in course of supply for use at Harwell or at other A.E.A. establishments.



Developed by Hoover Ltd. to the requirements of the A.E.R.E., Harwell, this vacuum cleaner is used for radioactive dust removal. Smooth-bore flexible plastics hose is used to prevent dust adhesion, the outlet pipe leading to a fume cupboard.

Of the cylinder type, the machine stands 1 ft. 5 in. high and is 2 ft. 2 in. long by 1 ft. 3 in. wide. The exterior parts are of steel and moulded plastic, and are coloured signal red as a warning of the possible radioactive contents.

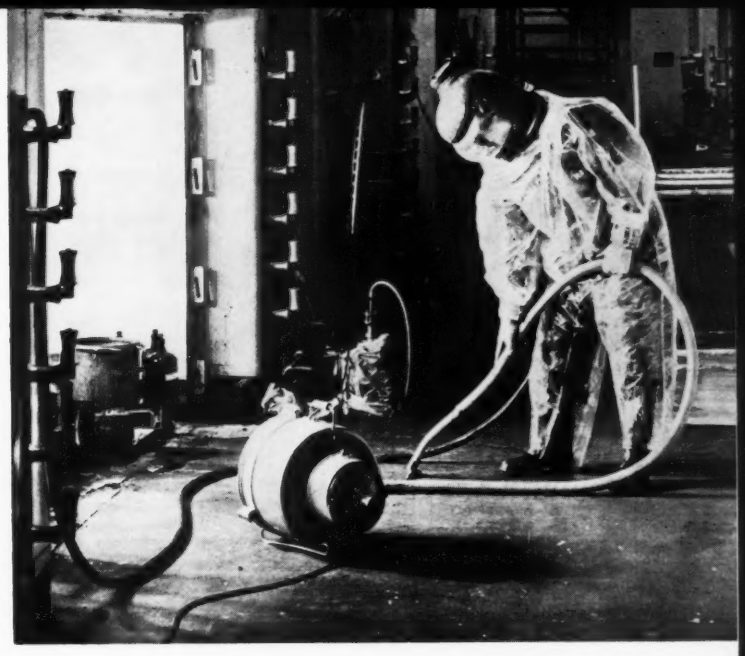
The hose used is of special design, made of flexible plastic and having a smooth bore to prevent adhesion of dust. The complete unit and its hoses are sufficiently water-proof to enable them to be hosed down with water for decontamination purposes.

The suction is provided by a fan driven by a ½ h.p. Hoover commutator motor, these parts being of normal design. From the inlet side of the machine the dust-laden air passes to two filters in cascade; each consists of two 13-in. diameter moulded cones placed back to back with the filter-

ing media clamped between them. The first filter uses a special cloth, the second a wool pad 1 in. thick impregnated with resin. The filters are said to remove dust particles down to 0.3 micron. A hose is provided on the exhaust side of the machine for the controlled disposal of the filtered air, if this should be considered necessary.

During use, the dust particles adhere to the filter diaphragms or fall to the bottoms of the units, which are designed so that they may be effectively sealed before removal from the cleaner, thereby protecting the operator from radioactive dust.

Periodic checks are made to determine the radioactivity of the filters and machine, and replacements are made when necessary. The useful lives of the parts may be of the order of two weeks for the cloth filter, four weeks for the wool filter and upwards of twelve months for the remainder of the cleaner, but these periods will vary with the usage of the machine.



The special Hoover cleaner in use at Harwell.

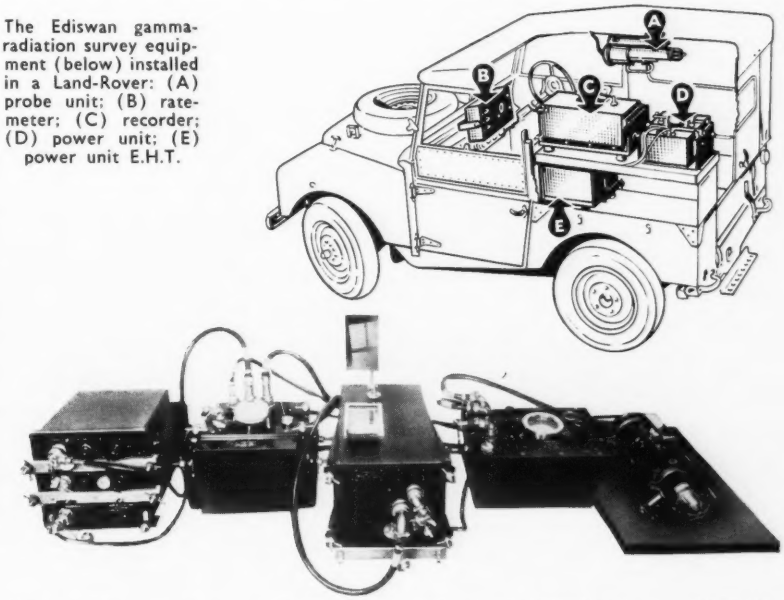
Mobile Uranium-Prospecting Unit

A highly-sensitive equipment for geological surveys has been designed and developed by the Edison Swan Electric Co. Ltd., in conjunction with the Atomic Energy Research Establishment at Harwell. It is intended for mounting on either a vehicle of the Land-Rover type or its equivalent. When in use, the vehicle is driven about until a signal is received. If necessary, either the driver or his passenger can dismount, taking with him the scintillometer probe for manual detection.

The sketch shows the five main items of equipment installed in a vehicle. The scintillometer probe unit will detect a change of $\pm 0.0005\%$ in 0.003% equivalent uranium oxide (U_3O_8) in bedrock. This probe is claimed to have a lower relative background than Geiger-Muller-type detectors in which cosmic radiation tends to mask terrestrial gamma radiation. The necessary signals are given by the ratemeter unit, which has a single compressed scale and an adjustable threshold alarm which flashes a light and sounds a bell. The time constant of the ratemeter and of the alarm is 1 sec. in each case. This ratemeter carries all the operating controls and is designed for mounting within easy reach of the driver or passenger. The recorder is of the inkless type, using Teledeltos paper, and moves at 12 in. (305 mm.) per hour with marker facilities for mileage, and so on. The time constant of of the recorder is 2-5 sec.

The current used for operating this equipment is 3.7 A from a 12-V battery. Stabilization is provided for variations from 11 to 14 V. All valves are of the cold-cathode type, which are largely responsible for the low internal temperature rise of the equipment when in operation.

All the units are fully "tropicalized", hermetically sealed and desiccated. Anti-vibration mountings are used and all interconnecting cables have sealed-type connectors. The separate units are quite small and can be disposed about the vehicle to the best advantage by reason of the 15 ft. (4.572 mm.) of interconnecting cables. The probe can be released quickly and, as mentioned before, used as a manual means of detection at close quarters, subject, of course, to the cable limitations.



The Ediswan gamma-radiation survey equipment (below) installed in a Land-Rover: (A) probe unit; (B) ratemeter; (C) recorder; (D) power unit; (E) power unit E.H.T.

The total weight of the five units with their connectors amounts to 98 lb. (44.5 kg.), made up as follows: probe unit, $14\frac{1}{2} \times 5 \times 5$ in ($368 \times 127 \times 127$ mm.) 6 lb. (2.7 kg.); E.H.T. power unit, $11\frac{1}{4} \times 9\frac{3}{4} \times 9\frac{3}{4}$ in. ($286 \times 248 \times 248$ mm.), 16 lb. (7.3 kg.); ratemeter unit, $14\frac{1}{2} \times 8\frac{1}{2} \times 7\frac{1}{4}$ in. ($368 \times 216 \times 184$ mm.), 14 lb. (6.4 kg.); power unit, $10\frac{3}{8} \times 14\frac{1}{4} \times 8\frac{5}{8}$ in. ($264 \times 362 \times 219$ mm.), 21 lb. (9.5 kg.); recorder unit, $19\frac{1}{2} \times 9\frac{1}{4} \times 9\frac{3}{8}$ in. ($495 \times 235 \times 232$ mm.), 27 lb. (12.2 kg.); and connectors, 14 lb. (6.4 kg.).

Processes and Equipment

Pressure Switch

A new indicating pressure switch with a 5-in. dial has been introduced by Appleby and Ireland Ltd., Kempshott, Basingstoke, Hants. As a combined vacuum and pressure instrument, it is available in the following calibrated ranges: 30 in. Hg. vacuum to 60 in. Hg. pressure; 760 mm. vacuum to 2 kg/cm^2 pressure; and 14.7 p.s.i. vacuum to 30 p.s.i. pressure. Instruments for pressure switching only are also obtainable. The switch, which is adjustable from the front, may be supplied to open or close contacts with increasing pressure, the switch rating being 5 amp., 250 V, a.c. An internal heater, to operate from 110 V, a.c., can be supplied.

Bracket for Thickness Gauge

The makers of the Atomat radiation thickness gauge—Baldwin Instrument Co. Ltd., Brooklands Works, Dartford, Kent—are now offering special mounting brackets to carry the measuring head. These are cast aluminium alloy C-brackets mounted on four ball-races to facilitate traversing and are available with 12-in., 27-in. and 42-in. throat depths, measured from the centre of the measuring head to the throat. The four standard gap sizes are ½ in., 1 in., 1½ in. and 2 in.

The bracket is made movable so that the head can be withdrawn or repositioned or continuously traversed. Manual or pneumatic operation is available.

The radioactive source, when used in a C-bracket, is fitted with a shutter which may be manually, electrically or pneumatically operated.

For a C-bracket to be used it is necessary to have a gangway by the side of the machine sufficiently wide to accommodate the bracket when fully withdrawn. In some installations the space is not available, and the makers are developing a special mounting consisting of two end pieces placed each side of the machine and joined by two tie bars, one located below the web and the other above. The source will move along the upper bar and the chamber along the lower.

Wire-mesh Filters

Aircraft Porous Media Inc., 30 Sea Cliff Avenue, Glen Cove, New York, have announced the development of Rigimesh wire-mesh filter elements. The mesh is made by furnace-welding the wires at all contact points and the design is such that it has plate-like characteristics which permit fabrication by cutting, rolling, corrugating and welding without loss of the original uniformity of mesh openings. The wire normally used is stainless steel but other metals and alloys can be specified if required. Two or more layers of the same or different meshes can be homogeneously bonded to form a laminate; in this way, assemblies combining fine filtration qualities with mechanical strength can be built up.

The present range of Rigimesh filters have particle-size retention ratings of 2 to 2,000 microns, and will operate at temperatures from −65°F to 900°F and at pressures from vacuum to 10,000 p.s.i.

Transistor Testing

A simplified transistor tester has been developed by Mullard Ltd. for use in circumstances where detailed information on the parameters of junction transistors is not necessary, but an indication only of general characteristics and conditions is required.

Compact and easy to use, the L264 equipment provides a means of checking base-collector short-circuit current gain, d.c. collector current for zero base current, and collector turnover voltage. All measurements are presented as direct meter readings.

The base-collector short-circuit current gain is measured at d.c., advantage being taken of the approximately linear relationship between collector current and base current, which permits finite changes of current to be used to measure this parameter to within ± 5%. Measurement of the collector current covers 0-2.5 amp. in six steps, to an accuracy of ±5%. Facilities are incorporated to vary the feed resistance and collector supply voltage to give three ranges of collector dissipation: the ranges are 0-18V on 2.5mW, and 0-85V on 25mW and 250mW.

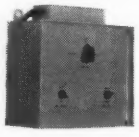
The instrument operates on 200-250 V, 40-60 c/s, single phase, with a consumption of 10VA. It is made by Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

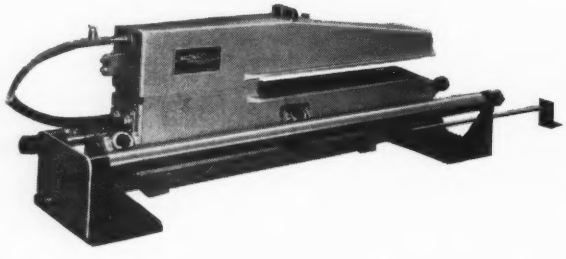
Remote Handling

Remote-handling equipment comprising tong head, vice and can opener and operating barrel and handle is being marketed by H.L. Instruments Ltd., 43 Poole Road, Westbourne, Bournemouth, Hants.

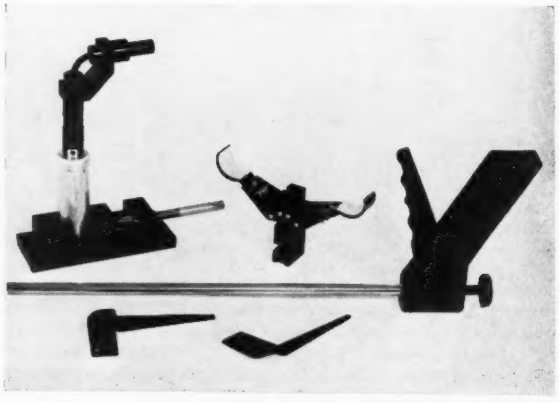
The handle is of black anodized aluminium alloy, incorporating a locking thumb screw. The barrel can be of stainless steel or chrome-plated mild steel with stainless-steel end fitting. The tong head is machined from solid brass, chrome-plated with satin-chromed mild steel jaws and stainless-steel hinge pins: a model in black anodized aluminium is also available. The attachments can be in aluminium or mild steel and are interchangeable. Those for holding can or beaker are sponge-rubber-lined.

Either mild steel or aluminium vices can be supplied. The can opener has a body of chromed mild steel, stainless steel or anodized aluminium. A strong duplex spring provides the rotary movement, but a bevel-gear system is also available.





(Above) The new C-type mounting bracket for the measuring head of the Baldwin Atomat thickness gauge.



(Right) Remote-handling equipment by H.L. Instruments Ltd.

New Polymerizing Paint

Pitakote, a new epikote resin paint, is a production of Allweather Paints Ltd., of 76 Great Queen Street, London, W.C.2. It is a two-pot paint, drying by polymerization instead of solvent evaporation, and particularly good resistance is claimed against attack from weather, seawater, alkalis, acids, oils, fats, solvents, and many other chemicals.

Flexible Glove Box

The glove cabinets for isotope handling made by Townson and Mercer Ltd., Croydon, are widely used. The latest addition to the range, however, is a non-rigid model made of welded P.V.C. sheet. These flexible cabinets are designed as really inexpensive substitutes for use where negative pressures are not required for safety: in fact, they are maintained at a small positive pressure by feeding in an inert gas or sterile air, any leakage merely acting as ventilation.

The P.V.C. is inert to most chemicals and, in the thicknesses used, resistant to tearing. The double-interlocking moulded P.V.C. zip fasteners used are airtight except for a small leak at one end. The main fastener encircles three sides of the square and allows the entire top to be folded back for ease of placing and adjusting apparatus without using the welded-on gloves or air-lock. The air-lock chamber at the side measures 12 in. wide by 8 in. high by 6 in. deep.

The cabinet itself is 24 in. wide, 22½ in. deep, 12 in. high at the front and 21 in. high at the back. Both main cabinet and air-lock can be separately inflated and a differential pressure maintained between them.

At the price of £15 it is virtually expendable for certain experiments.

Flexible glove cabinet of welded P.V.C. made by Townson and Mercer Ltd.

Survey Ratemeter

The Red Box geological unit is a fully sealed tropicalized ratemeter for the detection and measurement of gamma radiation. The metal case is watertight and contains a desiccator. It is easy to service, the whole of the lower part of the case being removable.

The batteries, with a life of over 600 hours, are of internationally available type and are housed in a container completely sealed off from the body of the instrument.

The high-voltage transistor circuit has been designed to accommodate a range of Geiger counters between 350 V and 450 V. The current is stabilized so that voltage fluctuation due to battery discharge causes no loss of accuracy.

The main switch has four positions: Off, Battery Test, Range 1 and Range 2. A full-scale meter deflection on a dose rate of 0.5 mr./hr. is provided on Range 1 and of 5 mr./hr. on Range 2. On both ranges it is possible to have audible

Red Box survey ratemeter.

indication by means of a plug-in deaf-aid-type earphone.

The instrument measures 7 in. × 5 in. × 1¾ in. and weighs 3 lb. with batteries and accessories. It is made by General Radiological Ltd., 15-18 Clipstone Street, Great Portland Street, London, W.1.

New Galvanometer

A sensitive taut-suspension galvanometer of robust and dust-proof construction has been placed on the market by Evans Electroselenium Ltd., Harlow, Essex. The Eel Unigalvo can be supplied as a current- or voltage-measuring instrument with range switch and terminals (Type 15), or as a current-measuring unit with stabilized power supply to facilitate the use of external photo-electric measuring instruments (Type 20).

The standard instrument has a scale sensitivity of 330 mm/μA (the equivalent of 1,500 mm/μA at 1 in.), 0.55 mm/μV with a coil resistance of 600 ohm, having a critical damping resistance of 15,000 ohm. Other sensitivities can be supplied. A range switch permits full, 1/10, 1/100 and 1/1,000 sensitivity.

A 15-cm scale having 100 divisions with side or centre zero is provided, but, if required, the instrument can be precisely calibrated and the scale marked in microamps or microvolts.

Transitrol programme temperature-controller.

Programme Temperature-controller

The Transitrol programme temperature-controller, Type 994, is a self-contained, direct-deflection instrument which indicates and controls temperature to close accuracy over a wide range in strict accordance with a predetermined time programme within a cycle range of 1 hour to 720 hours. Made by Ether Ltd., Tyburn Road, Erdington, Birmingham, 24, the instrument can be applied to any process where the signal can be converted into a direct current or voltage. The unit utilizes a transistor, eliminating the need for thermionic valves, magnetic amplifiers and oscillator circuits. It incorporates a conventional galvanometer used as the measuring system and an indicating pointer which operates a simple photo-electric system and controls the heating medium.

The specification of the unit is as follows:

Calibrated scale length: 6.5 in.

Calibrated accuracy: ± 1%.

Sensitivity F.S.D.: 65 microamp (average).

Internal resistance: 15 ohm per mV (average).

Minimum full scale: 8.5 mV.

Cold-junction compensation: fitted as standard.

Copper temperature coefficient compensation: fitted as standard.

Thermocouple break protection (T.C.B.): fitted as standard.

Control sensitivity: 0.15 of 1%.

Control-relay: single-pole change-over.

Contact ratings: 10 A, 115 V, a.c.; 5 A, 230 V, a.c. (non-inductive).

Power supplies (standard): 105/130 V and 210/260 — 50/60 c/s (selective tappings).

Power consumption: 2 VA.

All instruments are calibrated for 2 ohms external resistance (compensating lead and thermocouple). This value can be adjusted up to 10 ohms by means of a pre-set resistance mounted internally.

Panel cut-out: 13⅜ in. × 15¾ in.

Depth of case: 7 in.

Net weight: 45 lb.

List prices with "two-position on/off" indicating temperature controller, £85. With "anticipatory" indicating temperature-controller, £90 5s.

Delivery: 7 to 14 days.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 760,617. Plastic putty-like materials. To: Knapp Mills Inc. (U.S.A.).

An inexpensive reliable seal for openings, cracks and crevices which might become dangerous in equipment and buildings for atomic energy work. The material consists of a large proportion of metal powder particles with a small proportion of a soft coating and binding material (85% 200-mesh lead powder, 15% Texas Crater grease). Its density should be increased to about 9.5 by working the mixture to agglomerate the lead powder particles, forcing them to coalesce by minute welds.

B.P. 760,901. Window unit of scintillation detectors for alpha particles. W. A. Bayfield. To: Philips Electrical Industries Ltd.

Foils of an opaque material (aluminium) permitting the passage of particles are supported by tensioned nylon and silk threads secured by an adhesive such as shellac varnish. The assembly is mounted in a rigid frame.

B.P. 760,971. Pressure-relief valves for dense vapours. E. S. Allen. To: U.K. Atomic Energy Authority.

Vapour-relief valves are held open against spring load by (a) the vapour pressure; (b) the reaction of a high lift device, if fitted; (c) an inertia reaction force due to the momentum of the vapour. (c) is quite small in the case of steam but large for heavy vapour, resulting in considerable reseating delay. Valves designed to reseat after a 3% blow-down of the steam pressure are found to blow down at 50% with, for example, monofluorotrichlor-methane. To reduce the blow-off pressure loss, the inertia reaction force is reduced by a mushroom-shaped member with curved vapour guides on the underside, integral with the body of the relief valve. The reaction force is thus taken by the guides and not transmitted to the valve-closure member.

B.P. 761,050. Method and means for producing phosphors. R. Lapage, S. K. Hutchinson and K. T. B. Scott. To: U.K. Atomic Energy Authority.

Refers to the production from a melt of large mono-crystals of, for example, stilbene, anthracene, tolane or naphthalene, which may serve as phosphors for the measurement of nuclear radiation. A molten phosphor is slowly cooled in a sealed cylindrical vessel terminating in a cone with a baffle in the conical portion having a small hole (1 mm.) or a capillary extension from the apex with an "S" bend. Crystalline growth is initiated in the apex or its extension.

B.P. 761,051. Polymeric substances. A. Charlesby. To: U.K. Atomic Energy Authority.

Polyvinyl-vinylidene chloride, polyethylene oxide wax or cellulose nitrate are subjected to ionizing radiation sufficient to increase resistance to solvent action but not sufficient to change the mechanical properties measured at ordinary temperature. (Additional to B.P. 732,047.)

B.P. 761,090. Gauge for measuring curvature. L. N. Snell. To: U.K. Atomic Energy Authority.

A rigid three-point contact, either mechanical or electrical, is provided, the points being arranged at the corners of an isosceles triangle. Through the apex and the mid-point of the base a line is drawn, and on this line a metal capacity probe is located so as to be capacity sensitive to the convex or concave curvature of a surface in contact with the three points. The points may be hardened steel balls located in a cage of electrically conductive material. They may also be constituted by three short parallel rollers.

B.P. 761,252. Separation of metals. T. V. Healy. To: U.K. Atomic Energy Authority.

Refers to the selective precipitation of compounds from aqueous solutions. Aqueous solutions of metal nitrates, which form basic compounds at pH values up to pH 3, are treated with formaldehyde at a temperature at which formaldehyde reacts with the nitrate ion. The treatment is preferably carried out at the boiling point of the solution. At about pH 2 or 3, ferric iron precipitates from a solution of ferric, nickel, and chromium nitrates in a relatively pure form. Passage of the formaldehyde is then discontinued while the solution remains at boiling point until precipitation is complete. In a similar manner ferric iron may be separated from cerous nitrate and from copper. Zirconium and tin may be separated from nickel, chromium, copper and cerium.

B.P. 761,404. Method of and means for converting the energy of nuclear radiations into useful electrical energy. To: Radio Corporation of America (U.S.A.).

A semi-conductive body is irradiated and an electric potential developed between output contacts on each side of the irradiated barrier region, which then may be fed into a load circuit. The radioactive "battery" includes a cold (not thermionic) source of high-energy nuclear radiation, for example, emitted from one or more of such materials as polonium and uranium, strontium-90 or tritium, cobalt-60 and numerous other radioactive isotopes.

B.P. 761,773. Valve oscillator circuit arrangements. E. Franklin and D. Williams. To: U.K. Atomic Energy Authority.

For generating a stabilized high voltage direct current (rectified from an amplified a.c.) from a direct current source of lower voltage. A three-electrode cold-cathode valve has a trigger electrode with a separate auxiliary cathode to which a fraction of the d.c. output voltage is fed-back. This regulates the trigger break-down potential and consequently the amplitude of the a.c. waveform generated by the valve.

B.P. 761,878. Digital computing apparatus. E. H. Cooke-Yarborough. To: U.K. Atomic Energy Authority.

The apparatus incorporates means for storing multi-digit numbers in an interlaced manner so that the consecutive digits of a number, when stored, each occupies a minor time interval located in consecutively regularly recurring major time intervals; the digits associated with any one major time interval all have the same significance. For instance, six digit numbers represented by the words ARTIST: BUFFER: CONVOY: DECIDE, are stored in time relationship thus: ABCD: RUOE, and so on, so that the intervals between the digits (A-R-T-I-S-T) are regular (major clock periods) and four times as long as between digits A-B-C-D, etc. (minor clock periods). A number may be read from store by opening a gate at a preselected phasing. Two or more numbers may be read by opening two or more gates each during differently phased minor clock periods. The computer is time-saving and requires less storage capacity.

B.P. 762,432. Testing of solid material for determining specific radiation absorption capacity and apparatus therefore. To: Stamicarbon N.V. (Netherlands).

The sample is spread out as a layer. The irradiating (roentgen-ray) beam and the sample are moved at uniform velocity so that during a certain period of time the beam irradiates the whole or a predetermined fraction of the sample. The radiation which emerges and that which does not pass the sample material impinges on detectors connected to compensating means. These operate in accordance with the change of the intensity of the detected radiation to maintain the intensities equal or in constant proportion. The operations, which are a measure of the absorption capacities of the successive parts of the sample, are automatically integrated to give a single specific absorption capacity value indication for the entire sample. In the tests, use was made of a roentgen-ray tube with cobalt anode and beryllium window, operated with a 14-kV tension and equipped with an Fe filter.